CHAPTER 5

INTERIOR WIRING

At any Navy or advanced base, the electrical system consists of three parts: the power plant that supplies the electrical power, the distribution system that carries the electrical current from the generating station to the various buildings, and the interior wiring systems that feed the electrical power to the appliances and equipment within a building.

As defined here, interior wiring begins at the point where the distribution systems service leads are connected to the wiring from within the building and extends through each circuit of the interior wiring of the building to the last fixture installation.

In this chapter, we will discuss your responsibilities in meeting various code and specification requirements and a variety of techniques for installing, repairing, and maintaining interior wiring systems.

STANDARDS

The National Electrical Code© (NEC©) is prepared and published every 3 years by the National Fire Protection Association (NFPA). You should use the latest publication and volume reference. The NEC© is an accepted guide for the safe installation of electrical conductors and equipment. Its purpose is to safeguard personnel and buildings and their contents from hazards arising from the use of electricity. NAVFACENGCOM recognizes the NEC© and uses it as its minimum standard.

How does the NEC© minimize the dangers mentioned above? Briefly, the NEC© provides the following:

- Various methods of wiring and descriptions of materials

Techniques for wiring designs and protection

- Requirements of general and special equipment
- Special conditions and occupancy information
- A variety of tables and examples for calculations

The NEC© is a wealth of information that provides CEs with a strict to-be-observed guide that experience has shown minimizes electrical hazards to personnel and buildings and their contents.

Now, we are going to distinguish between three important electrical terms. As a CE, you will need to know the difference between the terms grounded, grounded conductor, and grounding conductor. Grounded, as defined by the NEC©, means connected to the earth or to some other conducting body that serves in place of the earth. A grounded conductor is a circuit conductor that is intentionally grounded. A grounding conductor is a conductor used in connecting equipment in the circuit of a wiring system to a grounding electrode or electrodes. As a CE, you should make it a point to learn the difference between these terms. You will see them and hear them discussed throughout your career. Use the NEC©, study it, and learn it. A working familiarity with this reference will prove useful to you, and, as you advance in rate, teach your junior personnel the importance of this valuable guide.

SERVICE ENTRANCE AND DISTRIBUTION PANELS

The starting point for interior wiring is the service entrance. It is connected to the service drop. The service entrance is made up of several components, but before we get into the specifics concerning the service entrance, let us look briefly at the wiring system used to supply a building.

The types of electrical systems that are to be installed are determined mostly by what the building is to be used for and the type of equipment that is to be used. Generally speaking, electrical loads are divided into four categories: two-wire, single-phase; three-wire, single-phase; three-wire, three-phase; and four-wire, three-phase.

WIRING SYSTEMS

The simplest wiring system is a two-wire, single-phase type, as shown in figure 5-1. This system is used

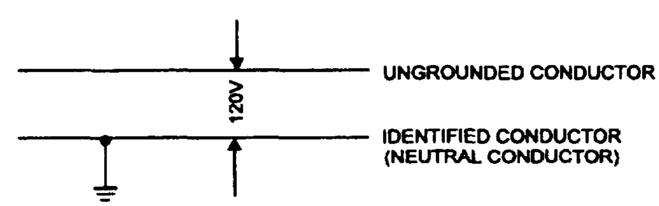


Figure 5-1.—Two-wire, single-phase system.

in small buildings where the primary requirement is lighting. It can also be used to operate 120-volt appliances and motors. The two-wire system consists of one ungrounded, insulated conductor and one identified (grounded) conductor, which is called the neutral. This system is limited to the operation of 120-volt equipment and relatively light loads of 50 amperes or less. Larger loads can be better served by another type of wiring system. The two-wire system requires the use of an equipment-grounding conductor that may be a separate conductor, conduit, or other recognized means of grounding.

Figure 5-2 shows the three-wire, single-phase wiring system, used both for lighting and power. This system, commonly known as "220," "110," (single phase), uses two ungrounded conductors and a neutral conductor, which is grounded. It provides 110 volts between each ungrounded conductor and the neutral. It also provides 220 volts between the two ungrounded conductors. This system is used for lighting and power loads, such as air conditioners and heating equipment. The three-wire, single-phase system provides up to twice the power that is available from a two-wire system with conductors of the same size provided that the load is balanced between the two ungrounded conductors. The 110-three-wire, 220 volts is the most common system used in residences today. This system also requires the use of an equipment-grounding conductor.

A second type of three-wire system is the three-wire, three-phase system shown in figure 5-3. This system is used to furnish power, usually 220 volts, to installed equipment. If some lighting is needed, 220-volt fixtures and bulbs can be installed, but be aware that there are certain restrictions placed on lighting circuits exceeding 120 volts. When substantial amounts of power are required, higher voltages, such as 480 volts ac, maybe provided with this type of system.

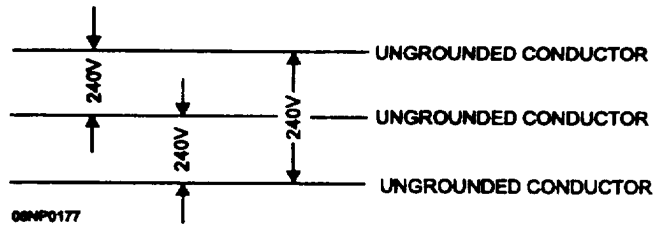


Figure 5-3.—Three-wire, three-phase system.

The last type of wiring system in common use is the four-wire, three-phase system (fig. 5-4). This system has three ungrounded phase conductors plus a grounded neutral. This system is a combination of light and power and offers quite a cost reduction over a three-wire, single-phase system for the same amount of power. The usual voltages are 120/208 or 120/240 VAC, depending on the type of transformer connections used.

SERVICE ENTRANCE

The service entrance serves to bring power from the service drop to the panelboard inside the building. One of the components of the service entrance is the conductors through which the current flows. The conductors may consist of individual wires run through a protective raceway, such as rigid metal conduit, electrical metallic tubing, or rigid nonmetallic conduit. The raceway provides the conductors with protection from both physical and weather damage. Power may also be brought into the building by means of service entrance cable. This cable does not need raceway protection unless it is likely to be physically damaged by abrasions or by being struck by passing equipment.

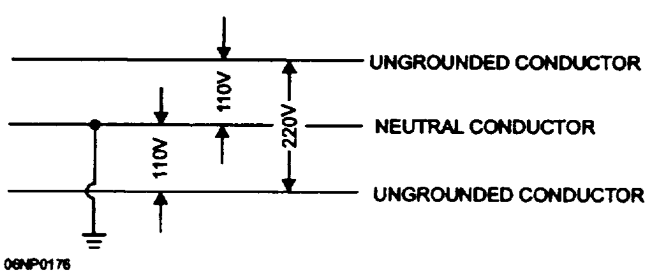


Figure 5-2.—Three-wire, single-phase system.

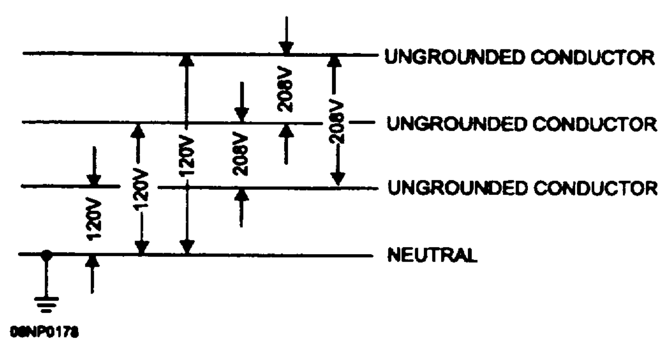


Figure 5-4.—Four-wire, three-phase system.

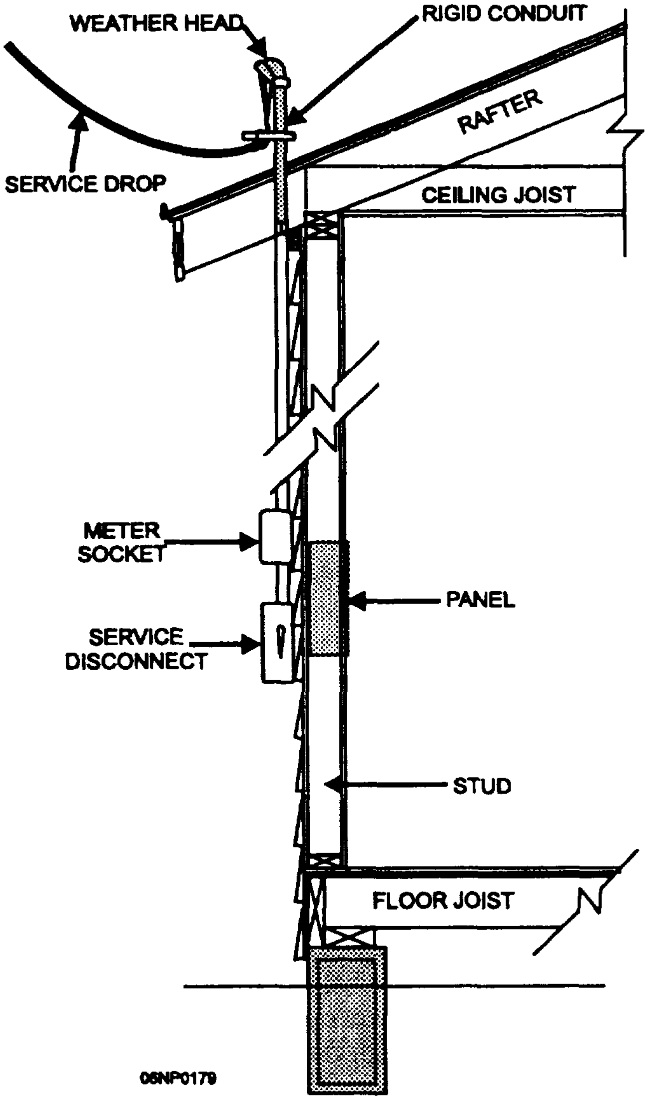


Figure 5-5.—Service mast service entrance.

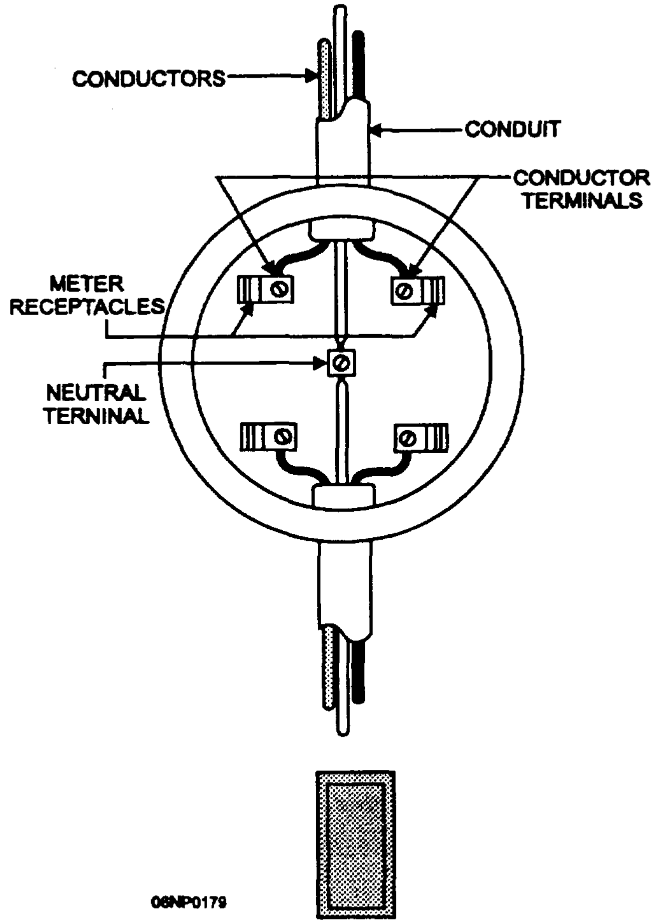


Figure 5-6.—Meter socket and wiring.

A weather head, also called a service head, as shown in figure 5-5, is used with a raceway to provide an exit for the conductors from the raceway. The weather head is designed to prevent the entrance of rain into the raceway. The conductor holes in the service head are designed to reduce abrasion to the insulation. Power delivered to the building may need to be measured to determine how much power is used. When this measurement is necessary, a watt-hour meter socket (fig. 5-6) is installed in the service entrance circuit so that a wattmeter may be included to record power consumption. Article 230 of the NEC© covers the service conductors and equipment for control and protection of services and their installation requirements.

SERVICE DISCONNECTS

The service entrance must provide a means of disconnecting the service entrance conductors from the interior building circuits. The service disconnecting means will be installed at a readily accessible location either outside of a building or structure, or inside nearest the point of entrance of the service conductors. A service disconnect, or main switch, can be used to turn off all interior power in case of a fire or other emergency conditions. A disconnect switch is also useful when work is to be performed on the panelboard or work is done on two or more circuits at the same time. Overcurrent protective devices are required for the service conductors in conjunction with the service disconnects.

Several types of service entrance disconnects are permitted. One of these is in the form of a knife-blade switch with one, two, or three blades, as needed, to open the circuit. Figure 5-7 shows a two-pole knife-blade disconnect. As you can see, this switch has two fuses directly beneath the movable blades. Another type of disconnect is installed as a fuse block. The fuse block contains a fuse for each ungrounded conductor. Removal of the fuse block has the same effect as opening a switch to interrupt current flow. A third method of providing for service disconnect and overcurrent protection is the use of circuit breakers. These may be installed as a multiple assembly with a single-switch handle. The service disconnect must be permanently marked to identify it as a service disconnecting means. The grounded conductor is not normally attached to the disconnect switch, but when it is, the switch must be in the form of a circuit breaker, and all the ungrounded conductors must open simultaneously with the grounded conductor. Regardless of whether it is switched, the grounded conductor has to be fixed so it can be disconnected. A terminal or bus bar to which all grounded conductors can be attached by means of pressure connectors meets this requirement.

The service entrance must be grounded to a low-resistance ground (refer to section 250 of the NEC©). Normally, a ground rod is driven into the ground for this

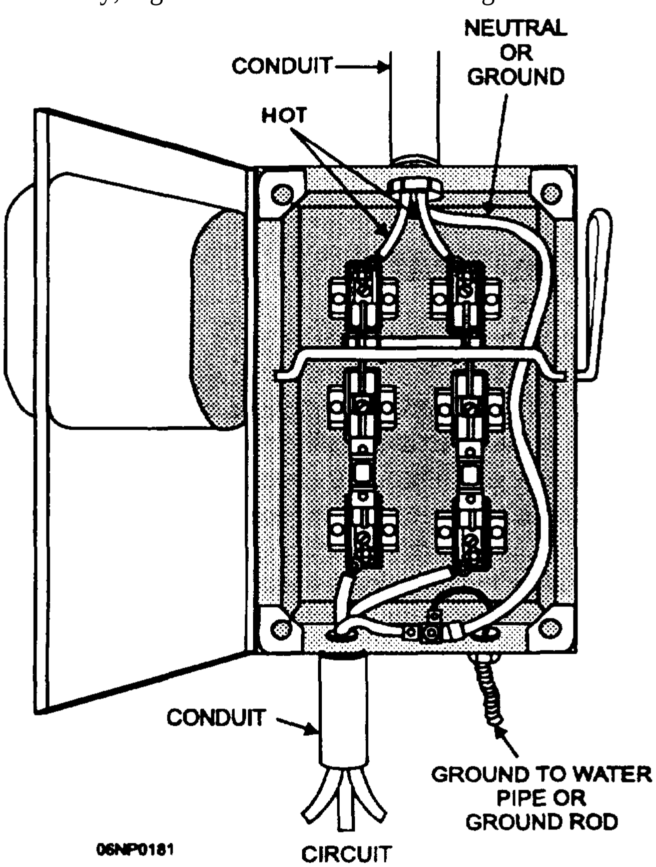


Figure 5-7.—Service entrance disconnect and overcurrent protection.

purpose, but a metal underground water pipe in direct contact with the earth for 10 feet or more and electrically continuous to the points of connection of the grounding electrode conductor and the bonding conductors may be used. Another way is to use the nearest available effectively grounded structural metal member of the building for grounding. Once a suitable grounding electrode is identified, the grounded or neutral conductor must be attached to it. The grounding electrode conductor is installed as a continuous conductor from the neutral bus bar to the grounding electrode. Small grounding conductors are enclosed in a protective metal covering that should be electrically continuous from the panelboard cabinet to the grounding electrode. Metal raceways, meter sockets, panelboard cabinets, and the grounding electrode conductor enclosure must all be electrically bonded together and to the grounding electrode conductor so as to be electrically continuous. This arrangement results in all metal parts and enclosures in the service entrance and the grounded conductor being at the same potential electrically.

INTERIOR WIRING SYSTEMS

Every interior wiring job you will be assigned will have its own particulars, depending upon what type of building or structure you are assigned to wire. Some of these particulars are whether to use rigid, flexible, or thin-wall conduits. The type of conductors you will use, whether single or a cable with multiconductors, such as Romex or flexible cord. These particulars, as mentioned above, depend on what type of job you are assigned, temporary or hard-wired, block or drywall construction. Use this information provided here to become familiar with installation requirements. Learn to use the proper cable, conductors, and conduit in the correct place. Make sure you are familiar with the various methods of bending, joining, and installing the various materials, and learn to select the proper fittings and accessories that you will need to install those materials. As you are referred to the NEC© throughout the chapter, look up the articles indicated This action will help you get acquainted with the NEC©. A good CE takes pride in doing a neat, safe, and proper job.

CONDUCTORS AND CABLE SYSTEMS

Electrical conductors generally consist of drawn copper or aluminum formed into a wire. They provide paths for the flow of electric current and usually have insulating material encasing the metal. The insulation material is provided to minimize short circuits and to protect personnel. Atmospheric conditions, voltage

Table 5-1.—Percentage of Current-Carrying Capacity of Conductors

NUMBER OF CONDUCTORS	PERCENT OF NORMAL CURRENT-CARRYING CAPACITY
4 through 6	80
7 through 24	70
25 through 42	60
43 and above	50

06NP0182

requirements, and environmental and operating temperatures are factors considered in the selection of the type of insulating material for a particular job.

Single Conductors

A conductor may consist of a single, solid wire or a combination of a number of solid wires (stranded) that are not insulated from each other and share in carrying the total current.

A stranded conductor has the advantage of being more flexible than a solid conductor, thus making it more adaptable for pulling through bends in the conduit.

Conductors vary in diameter. wire manufacturers have established a numerical system called the American Wire Gauge (AWG) standard. Table 8 of the NEC© shows how this numerical system eliminates the necessity for cumbersome, circular mil or fractional inch diameters in the description of wire sizes. Notice that the wire gauge numbers increase from 4/0 through 18 as the diameter of the wire decreases.

Size, Number, and Ampacity

The wire size most frequently used for interior wiring is No. 12 AWG, used as a solid or stranded copper conductor. Table 310-17, column 2, of the NEC© shows the allowable ampacity of a single conductor in free air. No. 12 AWG (for types FEPW, RH, RHW, THW, THWN, XHHW, and ZW insulation) to be 35 amperes. However, the minute that same conductor is not alone in free air and is placed in a raceway, cable, or direct burial, you see, by referring to table 310-16, NEC©, that its ampacity is reduced to 25 amperes, provided that not more than three conductors are in the raceway or cable. Table 5-1 of this training manual indicates the reduced ampacities for a variety of numbers of conductors in such a situation, according to the NEC©.

Suppose now that you have four to six No. 12 AWG wires in a conduit. The allowable current-carrying capacity would be only 80 percent of the normal, or 20 amperes. To ensure a current-carrying capacity of 25 amperes, you would have to use No. 10 wire that has a normal current-carrying capacity of 35 amperes, 80 percent of which is 28 amperes.

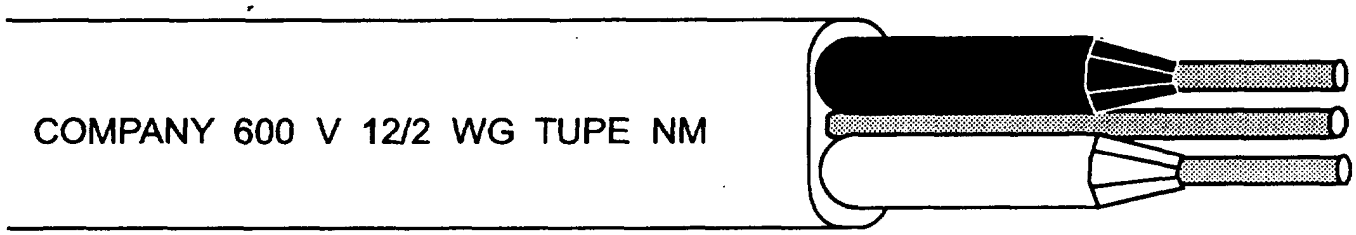
Cables

A cable is an assembly of two or more conductors insulated from each other with an additional insulating or protective shield formed or wound around the group of conductors.

Nonmetallic Sheathed Cable

Nonmetallic sheathed cable is more commonly called nonmetallic cable, NM cable, or Romex. Nonmetallic cable consists of two or three insulated conductors in an outer sheath. It may have an added insulated or bare conductor to be used as an equipment ground. The outer sheath is made of a moisture-resistant, flame-retardant, nonmetallic material either of thermoplastic or treated braid.

Nonmetallic cable has copper, aluminum, or copper-clad aluminum conductors. Copper conductors used in cable range in size from No. 14 to No. 2 AWG. The size of aluminum conductors is from No. 12 to No. 2 AWG. Specific descriptive information must be marked on the exterior of nonmetallic cable, repeating at intervals of at least every 24 inches. The information required to be shown includes the manufacturer's name or trademark, maximum working voltage, wire size, and cable type. Most cable is also marked to show the number of conductors and whether it has a ground, as shown in figure 5-8. The ground wire is used to ensure



06NP0183

Figure 5-8.—Markings on nonmetallic cable.

the grounding of all metal boxes in the circuit, and it also furnishes the ground for the grounded type of convenience outlets.

Nonmetallic cable comes in two types: NM and NMC. Type NM cable has a flame-retardant and moisture-resistant cover. Type NMC cable is corrosion-resistant. Its covering is flame-retardant, moisture-resistant, fungus-resistant, and corrosion-resistant. Refer to the NEC©, Articles 336, for Types NM and NMC uses permitted and not permitted.

In naval installations, Romex is used primarily for temporary work, such as on Quonset huts. Civilian contractors, however, use it extensively for residential wiring. All connections in Romex must be at the junction or outlet boxes. Saddle, straight clamps, or cable connectors must be used for securing the cable to the boxes. In installations where Romex is permitted, the ground wire is fastened securely to create a good mechanical and electrical ground. When a bend is made in Romex, the radius of the bend should be not less than five times the diameter of the cable.

BOX SELECTION

There is no firm requirement that a certain type of box be installed for a specific purpose. The usual practice is to install octagonal boxes for lighting outlets and to install rectangular and square boxes for switches and receptacle outlets. Round boxes are normally installed overhead for lighting purposes especially where the fixture canopy must cover the box. However, when the need arises because of inside space requirements, wall-surfacing materials used, number of electrical devices to be mounted, or the availability of boxes, almost any box can be used for any purpose.

The size and number of conductors to be installed in a box have a definite impact on the selection of a box. Each conductor in a box must have some free air space to prevent a buildup of heat. As a result, the more conductors, or the larger their size, the bigger the box must be in which they are installed. The cubic inch capacity of a box is determined by its length, width, and depth. An increase in one or more of these dimensions increases box capacity. When gangable boxes are assembled together, box volume is the total of all sections assembled together. Also, when a raised cover or a box extension with volume markings is added to a box, as shown in figure 5-9, its capacity is added to the volume.

The box to be mounted in each location is selected after the number and size of conductors it will contain are known In many cases, the usual box for the intended purpose is not adequate. To ensure proper air space for a conductor in a box, consult the table 370-16(a) for metal boxes in the NEC©. This table lists dimensions for common boxes, their cubic inch capacity, and the maximum permitted number of conductors in wire sizes No. 14 through No. 6. The number of conductors listed does not make allowance for fixture studs, cable clamps, grounding conductors, switches, or receptacles, or straps for mounting these devices. One conductor must be deducted from those listed when the box contains one or more fixture studs or cable clamps. Each strap containing one or more devices requires deduction of one conductor.

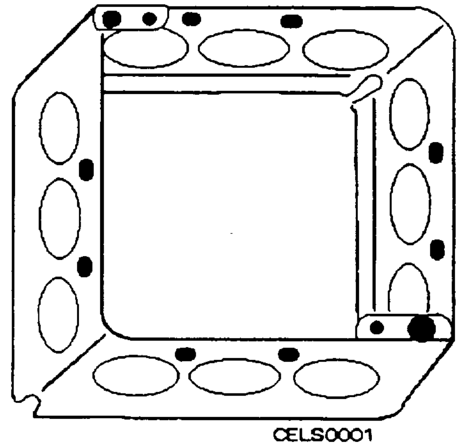


Figure 5-9.—Extension ring.

Also, one conductor is deducted for one or more grounding conductors that enter the box. A conductor that runs through the box is counted as one conductor. Each conductor that terminates in the box counts as one. Fixture wires and conductors that do not leave the box, such as an internal grounding wire, are not counted.

Let us use an example to see how the table works. Two receptacle outlets are to be installed using No. 12 nonmetallic cable. One of the outlets is to be installed as an extension to the other. Device boxes with cable clamps are to be used if possible. The first step is to determine the number of conductors that will be wired through the box. Two conductors plus a grounding conductor enter this box. Also, if a second outlet is to be connected to this one, then two conductors plus a grounding conductor must leave the box. If the preceding rules are followed, we have four conductors plus one for the grounding conductors, the equivalent of one conductor for the cable clamps, and the equivalent of one conductor for the receptacle outlet. This method gives us an equivalent of seven conductors. In looking at the table for metal boxes in the NEC©, we do not find a listing given for seven No. 12 conductors in a device box. There are a couple of listings for eight conductors; one indicates a device box 3 by 2 by 3 1/2 inches is required. Since there will be an equivalent of just five conductors in the device box for the second outlet, the table shows a 3 by 2 by 2 1/2-inch box to be adequate.

The table does not cover all the requirements for conductor space in boxes. Boxes of 100 cubic inches or less, not covered by the table, and nonmetallic boxes are marked with their cubic inch capacity. When these boxes are used or when conductors of different sizes are installed in the same box, the number of conductors allowed in a box is based on the free air space requirement for each conductor. The free air space needed is given in table 370-16(b) in the NEC©. According to the table, the volume of space needed in cubic inches per conductor is 2 for No. 14, .2 1/4 for No. 12, 2 1/2 for No. 10, and so on. As an example, if a box is to contain four No. 10 conductors and two No. 12 conductors, multiply 4 times 2 1/2 and 2 times 2 1/4. This equals 14 1/2 cubic inches, the minimum sized box that can be installed.

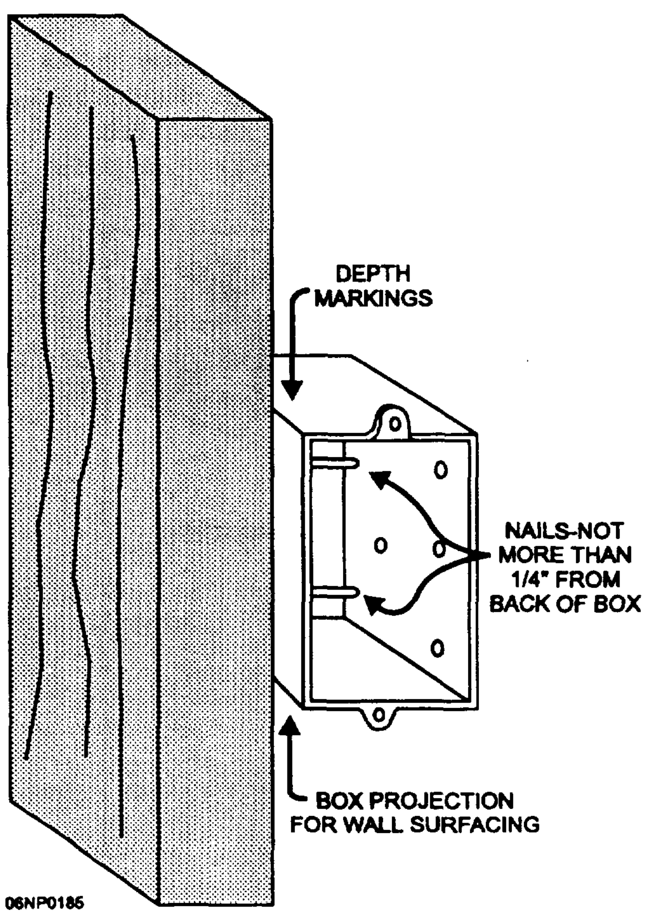


Figure 5-10.—Box installed with nails.

Outlet and junction boxes are installed in a number of ways in either new construction or an old building. Article 370 of the NEC© gives the installation rules for outlet, switch, and junction boxes. In most cases, boxes in new construction are fastened with nails or screws. Usually, nails are preferred because they are cheaper and quicker to use. Unless the box has a bracket on it, the side of the box must be removed to use screws for mounting. Some of the newer box mounting brackets have prepunched and preformed devices that are driven into wood framing to support the box in the place of nails.

Nail Through Box Mounting

One of the simpler boxes to mount is a device box. Boxes without brackets are mounted by putting two sixteen penny nails (3 1/2 inches long) through the holes in both sides of the box and then driving them into the wood framing member (stud). Nails that pass through the inside of a box must not be more than a quarter inch from the bottom (or back) of the box, as shown in figure 5-10. Also, note the markings on the side of the box. These are depth markings which let you easily install the box to project the proper distance from the edge of the stud to offset the thickness of the wall material that will be installed. Another way to mount device boxes with sixteen penny nails is shown in figure 5-11. In this case, the nails are outside the box, eliminating the possibility of wiring interference inside. The extension of the box sides, as is done here to provide for nailing, is often referred to as an S bracket mount. The bracket is made so that the nails can be driven in straight or on a slant, depending on whichever is easier. Being able to drive the nails at a slant is especially useful when the stud spacing is less than normal. The notches on the front outer ends of the bracket serve as a depth guide for mounting, the same as the markings mentioned before.

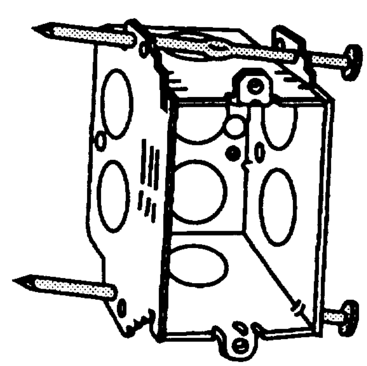


Figure 5-11.—S bracket box.

Many boxes come with attached brackets of various designs. Several of these brackets are shown in figure 5-12. The D bracket illustration is the simplest one of the group and is simply an extended box side. It is nailed or screwed to the stud. It also has notches to serve as an installation guide. The next bracket is the A bracket. As you can see, it is a straight bracket with a turned over upper edge that fits over the edge (face) of the stud. When nailed from both the front and side, this bracket makes an extremely strong mounting. The A brackets come attached to the boxes at varying distances from their edges to allow for use with different thicknesses of wall material.

The B bracket is made to fasten the box to the face of the stud. It has a couple of spurs that, when driven into the stud, hold the box in place while it is being nailed. The bracket may be attached to the box so it projects slightly above the edge, as shown in the illustration. This bracket prevents the device cover and its holding screws from causing a bulge when sheetrock is used for the wall surface. B brackets on device boxes are located at various depths to coincide with the thickness of the finished wall. Some B brackets are about twice as long as the one shown. These brackets are suitable for mounting on doorway framing studs to place switches and their cover plates beyond the edge of the door trim. This same bracket may be attached to the end of a device box for the horizontal mounting of a switch or receptacle. The J bracket is used the same as any other bracket that is fastened directly to the side of a stud. The holes are slotted to permit the box to be toenailed. The bracket is flush with the edge of the box and has gauging notches for positioning. This bracket has a knockout that allows installation of conduit through the stud into the box. The FA bracket is similar to the D bracket, except the bracket is welded to the side of the box. It also has a positioning spur to assist in holding the box in place while it is being nailed The bracket is offset from the edge of the box one-half inch or five-eighths inch to allow for the wall material thickness. The FH bracket is similar to the FA bracket, except it has two barbed hooks that drive into the face of the stud. The bracket is welded flush on square boxes and offset one-half inch on device boxes. Driving the barbed hooks into the stud face and nailing the side make a very rigid mount. The W bracket is fastened to both the face and side of the stud to provide a rigid mount. Since it stands the box off to the side of the stud, it is used to provide clearance between switches and switch plates and doorway trim, as does the long B bracket.

Box Mounting on Metal Framing

Much modem construction makes use of metal framing members. The ones you are concerned with mostly are the studs and the doorframes. Boxes can be attached with sheet metal screws or machine bolts and nuts. However, special attaching devices are available. A special anchor, as shown in figure 5-13, provides a

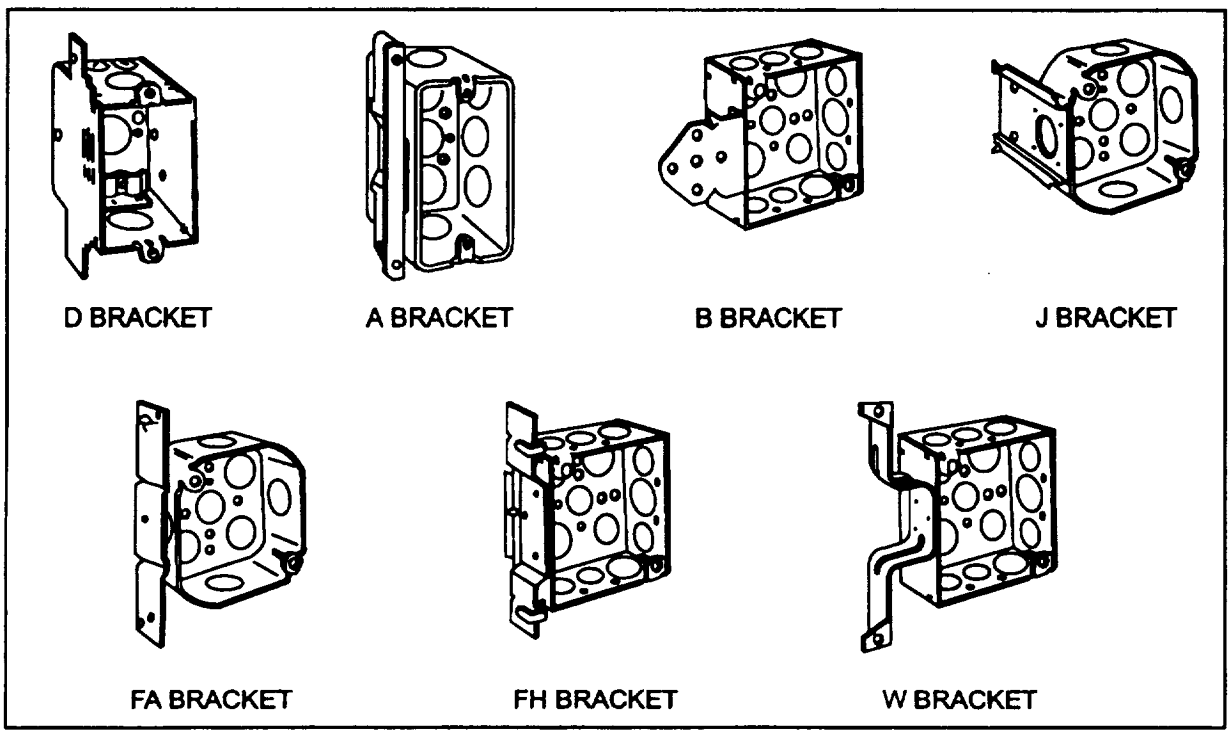


Figure 5-12.—Assorted box mounting brackets.

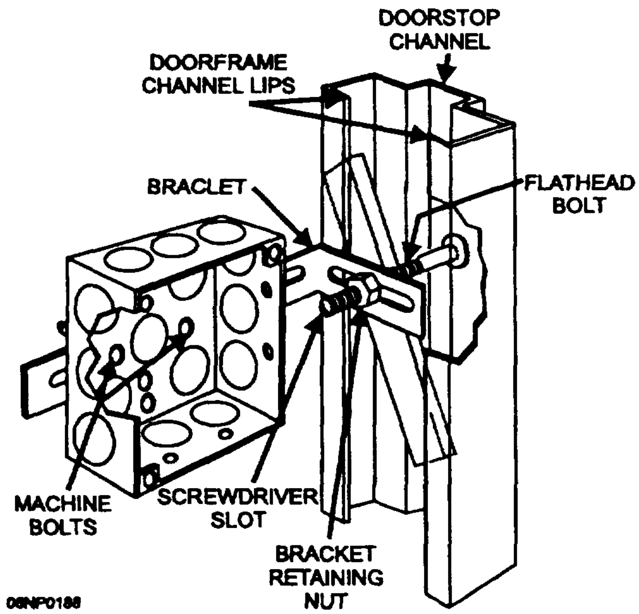


Figure 5-13.—Box mounting on metal doorframe.

quick, simple method of installing a box on the doorframe. This anchor allows the box to be adjusted in all directions; that is, toward or away from the frame, the depth from the outside wall surface, and up or down as needed. The nut on the bolt shown in the figure holds the bracket to the anchor and must be loose while the anchor is installed. The anchor itself consists of a flathead bolt with a screwdriver slot and a threaded channel. The channel comes in two sizes; one for narrow doorframes not over 4 inches wide and a second for doorframes up to 7 inches wide. The anchor is set in place by inserting it in the frame channel with the flathead of the bolt toward the doorstop channel and the threaded channel under the lips of the doorframe. The anchor is locked in place by inserting a screwdriver in the slot of the bolt and turning it clockwise until tight. As you can see in the figure, the bracket is adjustable and is held in position by the tightened nut on the bolt. The box is adjustable toward or away from the doorframe and is attached to the bracket with two machine bolts and nuts.

Metal spring clips provide a quick and easy way of mounting boxes onto metal studs. The same clip will work on studs of more than one design and size, such as 1 5/8- to 3 5/8-inch C channel studs and the truss type of studs. They are designed to mount square boxes with cover plates and to permit device boxes to be flush-mounted with various thicknesses of wall surfacing. A metal spring clip is shown at the left in figure 5-14. To mount a box, tap the clip over the open edge of the box. Then tip the box so the upper prong slips behind the face of the stud, as you can see at the right in figure 5-14. Press the lower prong back with your thumb until it slips

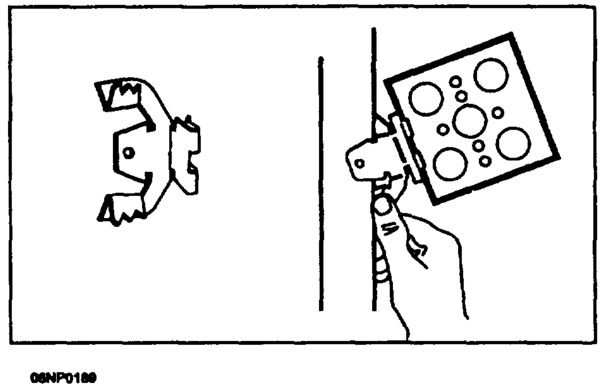


Figure 5-14.—Box mounting on metal stud with spring clip.

behind the stud face and locks the box in place. The box can be moved easily up or down on the stud by releasing the spring tension. Boxes can also be attached to metal framing members with sheet metal screws or machine bolts and nuts.

Box Mounting Between Framing

At times, boxes must be mounted between the building or wall supports instead of directly on them. This positioning is particularly true of ceiling lights where the joists do not coincide with the spot at which the light is to be placed. In such cases, boxes must be mounted on a separate support attached to the structure. These supports may be purchased in the form of bar hangers or metal straps, or they may be constructed from metal straps or wooden strips. Figure 5-15 shows

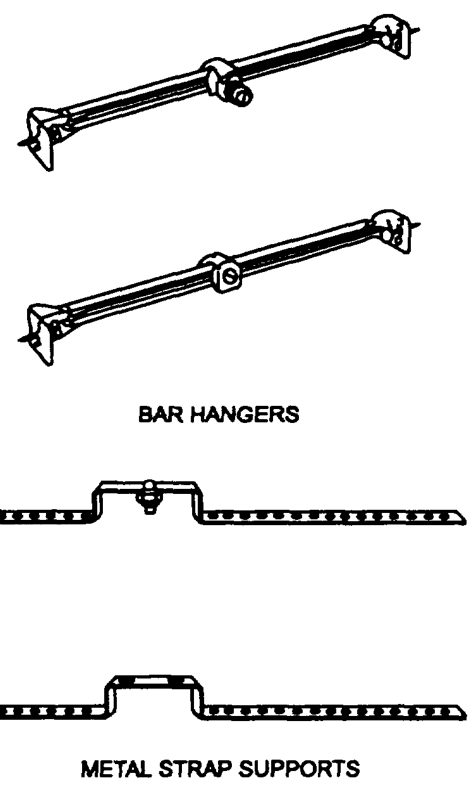
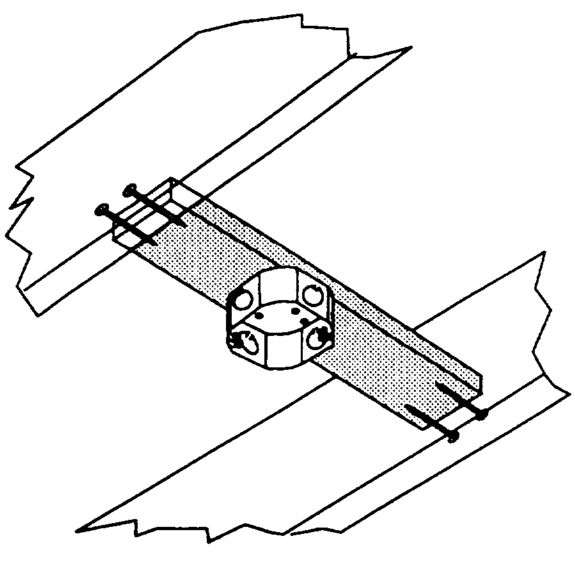


Figure 5-15.—Box supports.

two typical bar hangers and two metal strap supports. You can see that one of the bar hangers includes a fixture stud that also serves to support the box when it is installed through the knockout in the box bottom. The other bar hanger supports the box by means of a clamp installed through the bottom knockout. Bar hangers with boxes already attached are available. Bar hangers come in different lengths with each having a range of adjustment to fit spaces of varying widths. Bar hangers are fastened in place by nails driven into the side of the joist or stud. Sheet metal screws or machine bolts and nuts are substituted for nails when metal framing is involved. Metal straps may have fixture studs or may have slotted mounting holes so the box may be attached with machine bolts and nuts. Strap supports come in different lengths with several nail holes in each end to fit various width spaces. Strap supports are nailed to the face of the joist or stud They have different offsets to fit different box depths or installation needs.

Metal strap supports can be made similar to the manufactured one shown in the lower part of figure 5-15. Hole locations should be determined and holes drilled as needed for the specific installation being made. Wood supports can be made in a number of ways. About the simplest form is shown in figure 5-16. It consists of a piece of 1- by 4-inch lumber cut to length to fit between the joists and nailed in place. You need to allow for the depth of the box plus the thickness of the ceiling material when positioning the board for nailing. In some cases, two 1 by 4s may be nailed up with the wide dimension perpendicular to the joist or stud faces and the box mounted between them. Sometimes the ends of the 1- by 4- by 4-inch support is nailed to 1- by 4- by 4-inch blocks which, in turn, are nailed to the joists.



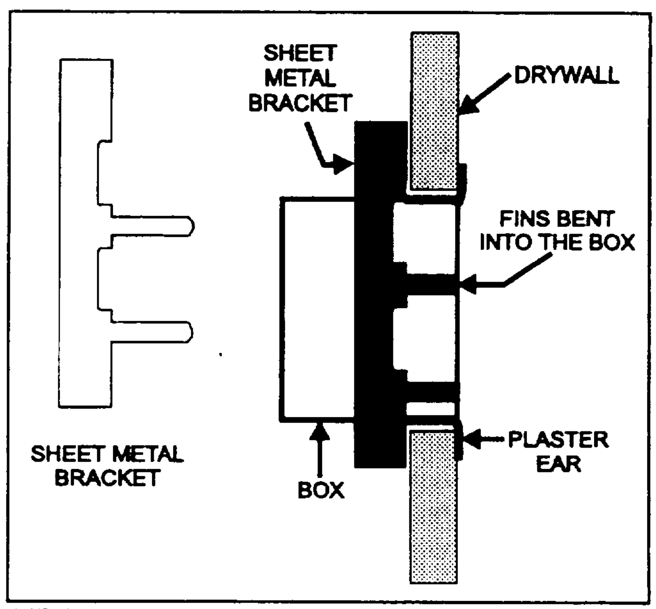
06NP0191

Figure 5-16.—Woodbox support

Box Mounting in Existing Structures

A completely different method of box mounting is required when a concealed extension is to be made to an existing circuit or when a new concealed circuit is to be added in an existing structure. The procedures discussed here pertain to mounting boxes in hollow walls; that is, walls, such as sheetrock or plaster on studs. Boxes must be equipped with plaster ears to assist in anchoring them in place. One method of hollow wall mounting is shown in figure 5-17. This method uses two sheet metal brackets to hold the box in place. The first step for this type of mounting is to locate and cut the mounting hole. After the hole is cut, hold the box in place in the hole with the plaster ears against the wall. Slip a bracket with the fins pointing out, long end first, between the box and the wall. Slide the bracket up until the short end clears the hole. Rush the short end into the hole and slide the bracket downward to center the fins with the box. Bend the fins tightly over the box edge and down against the inside. Repeat these steps for the second bracket. The box should now be held firmly in place.

A second method of mounting a box in a hollow wall makes use of clamping devices attached to the box sides, as shown in figure 5-18. These boxes usually come with a stiff paper template to outline the hole that must be cut into the wall. If you do not have a template, put the box against the wall and draw around it. Be sure you do not include the plaster ears in your drawing. Cut the hole as indicated, Slip the box into the hole and tighten the clamping screws until the box is firmly anchored. One variation of this method works quite



06NP0192

Figure 5-17.—Bracket support of box in hollow wall.

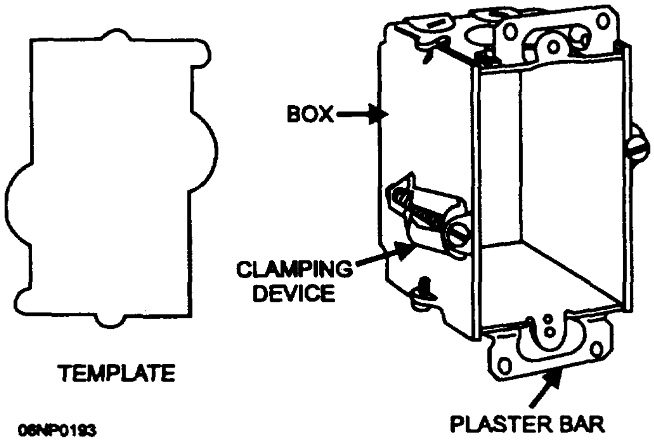


Figure 5-18.—Box with hollow wall clamps.

prepared hole and press on the bolt head until the ends of the support spring clear on the inside. lighten the bolt with a screwdriver until the box is held securely in place.

well with a lath and plaster wall. On the side of the box are cleats that unfold when the screws are tightened and clamp behind the lath. In this way, they support the ends that were cut when the hole was made.

A third means of fastening a box in a hollow wall uses a support that is added to the box through the knockout in the back. The application of this support is shown in figure 5-19. After the knockout is removed, assemble the support to the box by inserting the bolt with the retaining washer through the knockout hole. Thread the bolt into the support Rush the box into the prepared hole and press on the bolt head until the ends of the support spring clear on the inside. lighten the bolt with a screwdriver until the box is held securely in place.

Box Mounting Height and Location

There are no specific requirements for mounting boxes at a certain height. Mounting may be at any convenient height that meets the need for which the box is being installed. All boxes for the same purpose should be mounted at the same height. In some extreme cases, receptacle outlet boxes have been mounted in the wall parallel to the floor and just high enough to permit the cover plate to be installed. This type of installation requires that an allowance be made for the base finishing material as well as for the wall material when box depth is set. Receptacles set against the floor are hard to use and are hazardous in places where floors are mopped.

Heights for receptacle outlets and switches are usually given in the plans. The measurement may be from either the subfloor or the finished floor and may be to the bottom of the box; the center of the box, which is probably the most common; or the top of the box. The most popular height for receptacle outlet boxes in the living areas of a house is 12 inches from the floor line to the center of the box. Many electricians mark their hammer handles to use as a guide for installing outlet

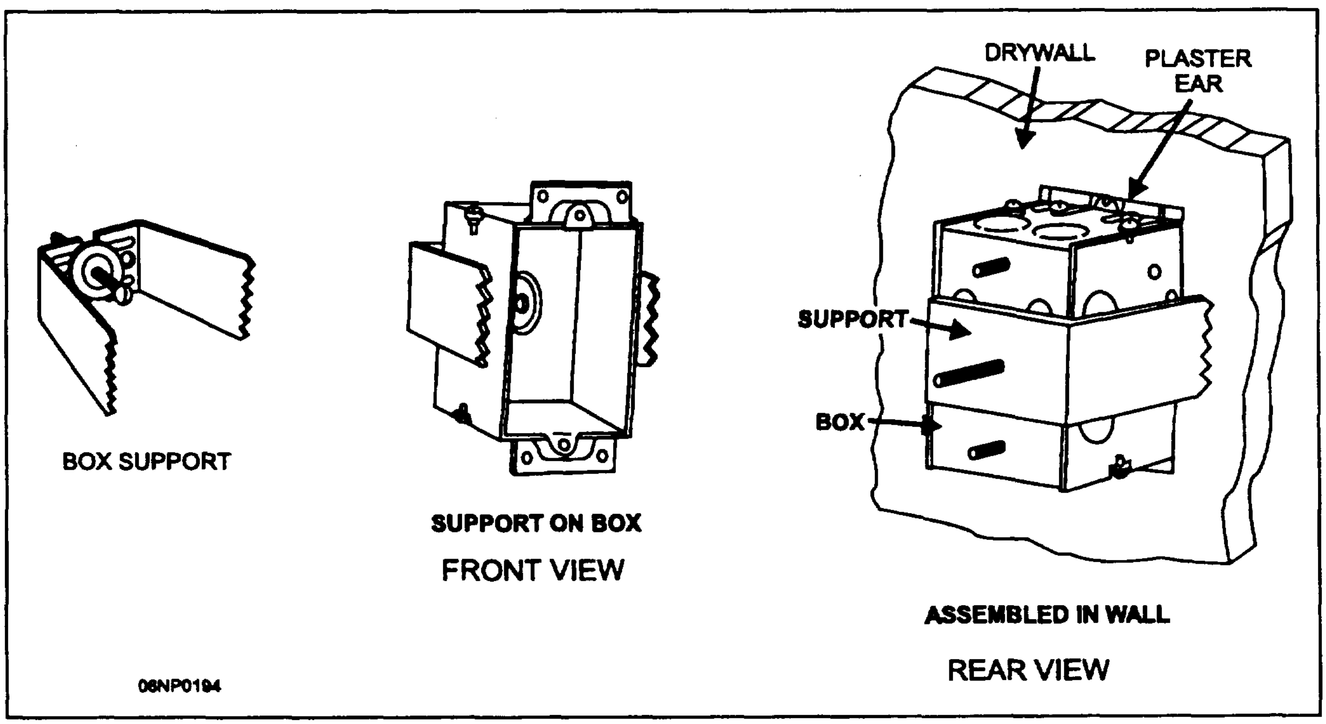


Figure 5-19.—Box support for hollow wall.

boxes at the proper height, as shown in figure 5-20. Any number of other guides, such as a rule or a notched stick, can be used.

It is a fairly common practice to mark the exact location of each wall-mounted box on the studs throughout the building before mounting begins. A lumber crayon, carpenter's pencil, or felt-tip pen that makes an easily seen mark should be used. An arrowhead, like that shown in figure 5-20, is used to show where the center of the box is to be placed. The arrowhead also points to the side of the stud where the box will be put. As an added convenience, symbols may be marked near the arrow to indicate the types of device to be installed. Some examples might be XX for a duplex outlet, SS for two single-pole switches, S3 for a three-way switch, or XR for a range outlet.

Switch boxes and outlet boxes for laundry and utility rooms and garages are normally set 4 feet above the floor. This height is often increased 4 to 6 inches when some type of wainscoting or paneling 4 feet high is to be included as part of the wall. Boxes for outlets over counter tops are usually installed about 18 inches above the counter top (see NEC Article 210-52(c)(5)). This measurement can vary a few inches up or down, depending on the height of the backsplash panel. Installing boxes without considering the splash panel could cause you to have boxes that overlap different wall surface levels.

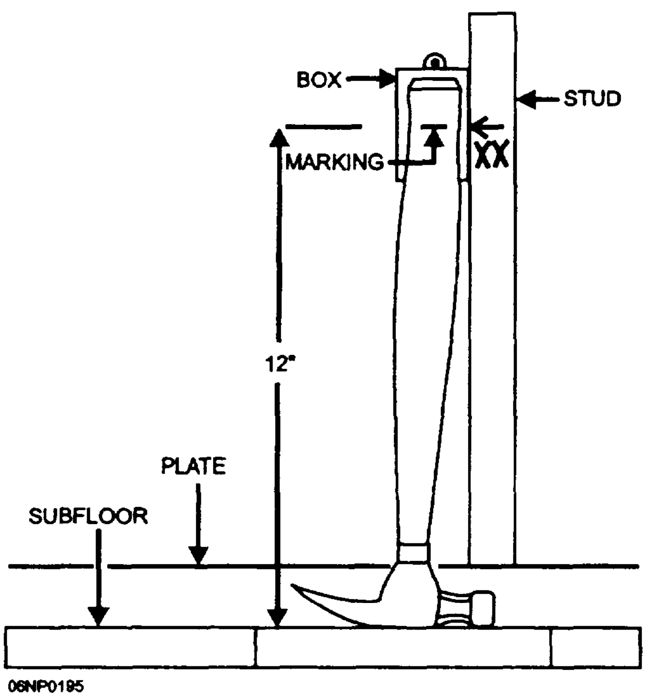


Figure 5-20.—Measuring box mounting height.

Ceiling boxes are located by a completely different method of measurement. Most rooms have at least one ceiling light located in the center of the room. A number of ways can be used to find the spot to mount this light box. One way is to use a rule or tape to find the halfway point across one dimension of the room and mark it, as shown in figure 5-21, view A. Make a second measurement across the same room dimension and mark the halfway point. Connect the two marks. Measure the other room dimension to find the center and mark it on the preceding line. This point is the place for the ceiling light box. Figure 5-21, view B, shows another way to spot the ceiling box. Run diagonals with string from opposite comers of the room. The point where the diagonals cross is the room center. Sometimes the position of the box is laid out on the subfloor. The point is then transferred to the ceiling by use of a plumb bob (a pointed weight on a string). When the plumb bob is suspended by a string held at the level of the ceiling joists with the point of the weight over the desired location, the top of the string will be at the spot where the box is to be mounted.

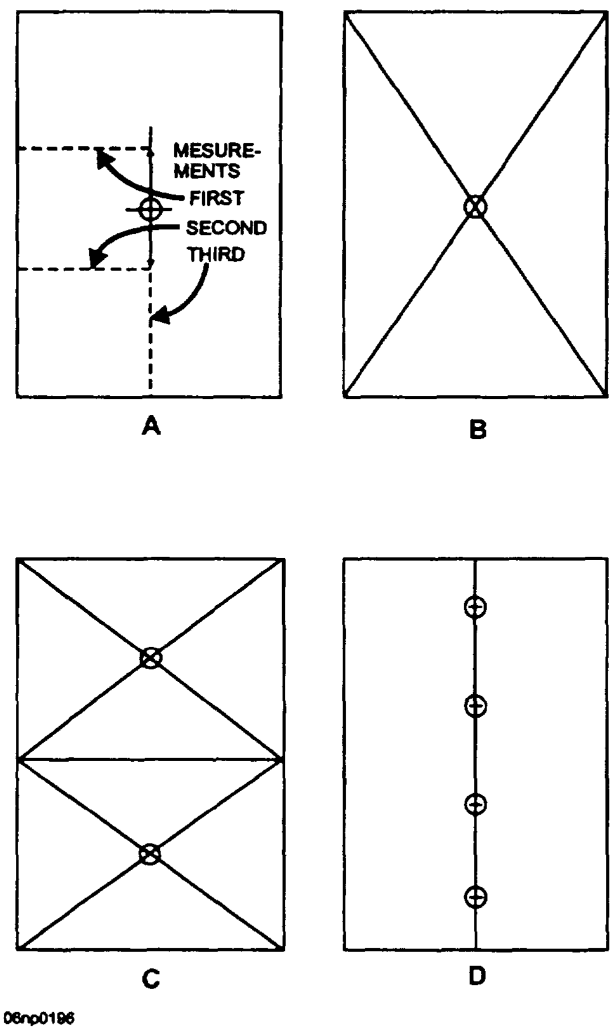


Figure 5-21.—Location of ceiling lights.

Many rooms require multiple ceiling lights. If only two lights are involved, measure half the length of the room and then run diagonals for each half, as shown in figure 5-21, view C. This measurement procedure gives you the location for each light. A room that is to be lit with a row of lights will have them installed along the center line. The lights should be spaced so that the lighting is as uniform as possible. You can determine the spacing by dividing the length of the room by the number of lights. This figure is the space that is to be left between any two adjacent lights. The light at each end of the row is placed at half the preceding distance from the wall. This spacing is shown in figure 5-21, view D. If you take another look at view C, you will see that the space from the end walls to the lights is also half that of the space between the lights.

INSTALLATION OF NONMETALLIC CABLE

Installation of electrical circuits with nonmetallic cable is fairly simple. It is usually done in two stages. The two stages are called roughing in and finish work. Roughing in is the work done before the walls and ceilings are put in place, and finish work is just what it implies, the finishing up. You splice wires as needed and install the receptacle outlets, switches, and lighting fixtures.

ROUGHING IN

The main objectives in roughing in are to get circuits routed properly, to reduce the chance of damage to the cable during installation, and to reduce the chance of damage while the structure is being finished or during later modifications. You should refer to Article 300 NEC© for wiring methods.

When roughing in your circuits, study your electrical blueprints. They will show the general location of the outlets and switches and how the cable is to be routed. The exact spot where each outlet and switch are to be put is determined by the requirements of the NEC© and the experience of you, the electrician, unless specific directions are given.

A straight line is the shortest distance between two points. This principle is used a great deal of the time by electricians when they are routing cables. Cable is run from box to box by the shortest route unless there is a good reason not to do this. Such routing does not always look neat, but it keeps the cost of material and labor down, and since most wiring is concealed, it is not often seen.

Cable must be fastened in place to support it and to prevent strain at boxes and connections. Cable must be anchored within 12 inches of a box, cabinet, or fitting and at points no more than 4 1/2 feet apart between boxes. NM cable is usually attached to wooden framing studs by staples (fig. 5-22). Care must be taken not to drive the staples in tight enough to damage the cable. Another method for securing Romex is by the use of straps. Figure 5-23 shows four types of straps that may be used to secure cables.

Concealed cable is installed either through holes bored in wooden framing studs or into notches cut in their edges. Holes can be bored with various sixes of bits, depending upon the size of hole needed. The holes should be drilled in the center of framing studs in a straight line and at the least possible angle either

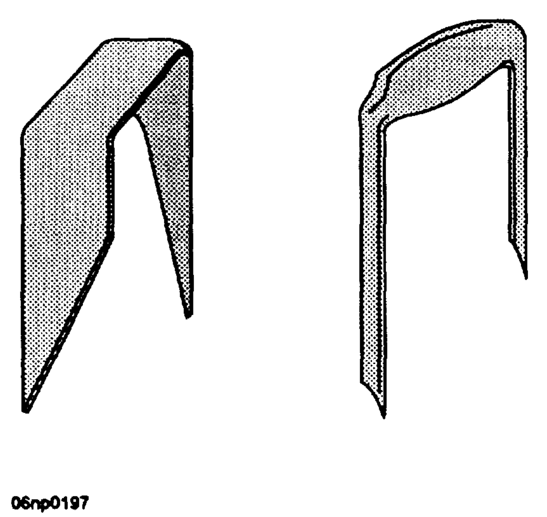


Figure 5-22.—Nonmetallic cable staples.

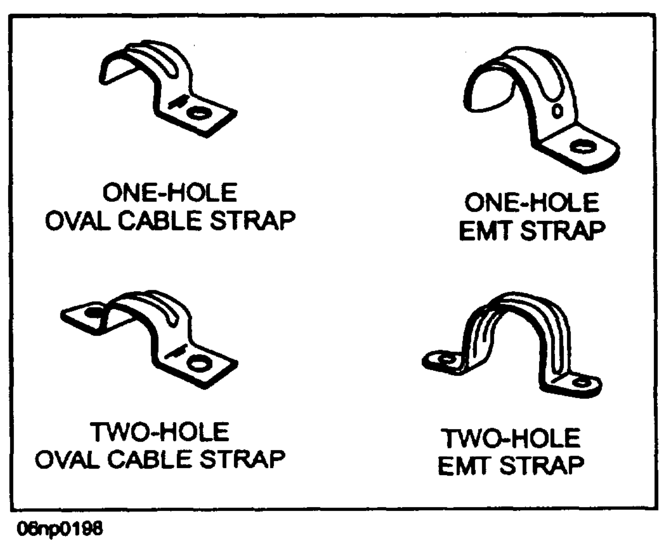


Figure 5-23.—Straps for fastening cable.

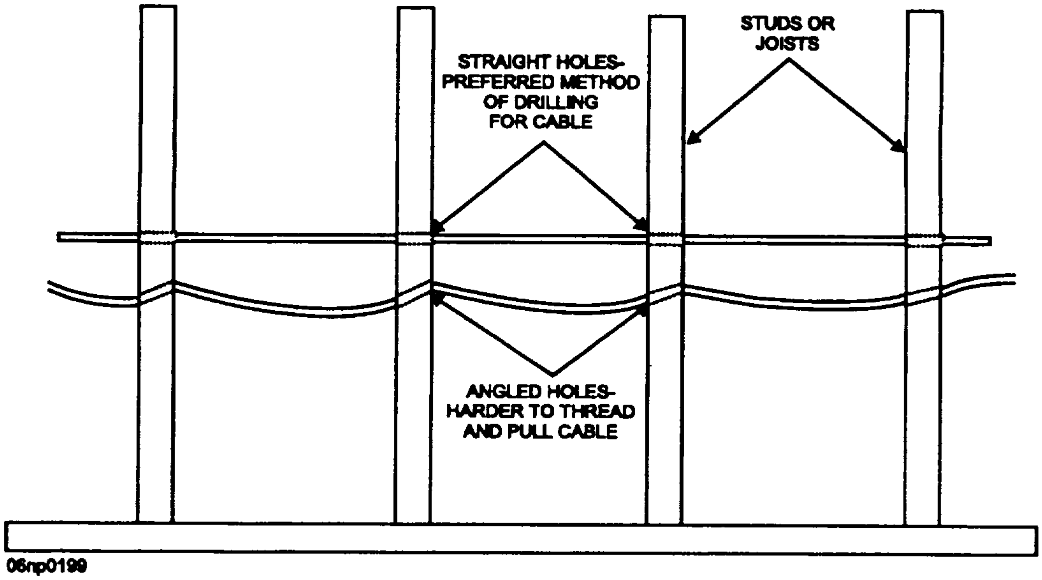


Figure 5-24.—Drilling holes for nonmetallic cable.

vertically or horizontally, as shown in figure 5-24. Holes that are drilled in a crooked line or at much of an angle to the line of pull, as shown at the bottom of figure 5-24, make it harder to thread the cable through the holes and pull it into position.

Cable can be placed into notches cut in the edge of the framing members and studs, as shown in figure 5-25, if the notches will not weaken the building structure. The notches should be as small as possible. Their depth must not exceed one fifth of the width of the wood. Cable placed in notches or through studs is protected from nails and screws by a thin metal plate at least one-sixteenth inch thick, according to the NEC©, Article 300-4, like those in figure 5-25.

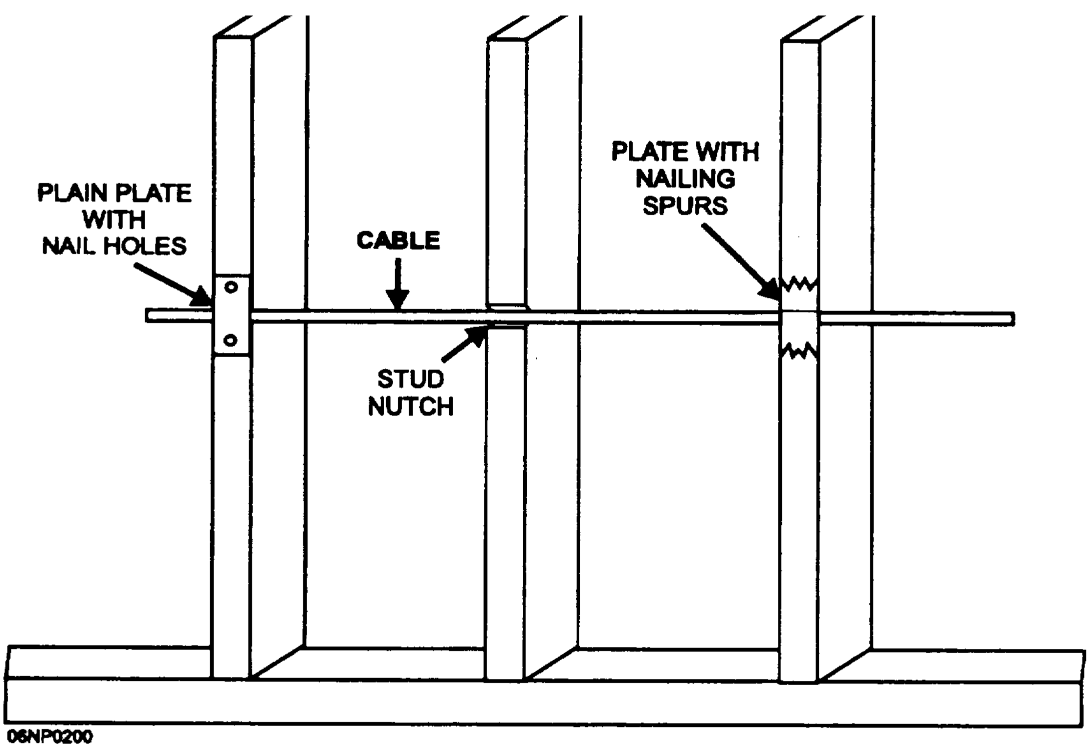


Figure 5-25.—Nonmetallic able installed in notches.

Cable is installed through metal framing members in about the same way as it is in wooden ones. Either holes or slots are used and they must be cut, punched, or drilled at the factory or in the field. Normally, holes in metal members must have bushings or grommets inserted securely to prevent damage to the cable covering. If holes or slots have been formed so that no metal edge can cut or tear the cable insulation, bushings or grommets are not needed. Use good judgment when deciding whether or not grommets are required. A steel sleeve, plate, or clip must be installed for protection wherever a cable might be punctured or cut by a nail or screw.

The first step in wiring a building after the distribution panel or panels have been installed is, in most cases, to mark the location of the outlet boxes. Then mount the boxes in place unless the mounting of a box might interfere with hole boring or cable anchoring. Once the boxes are in place, make the needed holes or notches for the installation of the cable. Install the cable by starting at the free end. Strip, as a minimum, 6 inches of the outside covering from the cable end. If the box has cable clamps, remove one of the knockouts and insert the stripped cable end through the hole under the clamp until one-fourth inch of the cable cover extends beyond the clamp. Tighten the clamp to hold the cable firmly in place, but be careful not to overtighten as this procedure could cause a short. This procedure will give you conductor ends 6 inches long in the box, as shown in figure 5-26. You need these ends so you can make splices or attach devices or fixtures easily. Remember to anchor the cable within 12 inches of the box, as shown in figure 5-26.

Boxes without cable clamps require a little different procedure. After stripping the cable end, remove one of the box knockouts. Then install a cable connector, similar to the ones in figure 5-27, in the knockout hole. Install the locknut so that it points inward to dig firmly into the metal box as shown in figure 5-27. Put the cable end through the connector to expose one-fourth inch of the outer cover, and then fasten it in place, as shown in figure 5-25.

After the free end of the cable is in the box, work the cable back toward the other box. Run the cable along the framing members, fastening it at points no more than 4 1/2 feet apart. When you get to the other box, cut the cable to length, allowing for 6 inches of free conductor in the box. Strip the outside covering, insert the cable end, fasten it to the box, and anchor it within 12 inches of the box. To help avoid damage to the wires as wall coverings are being placed and other construction is being done, make sure you tuck back the wires into the outlet box.

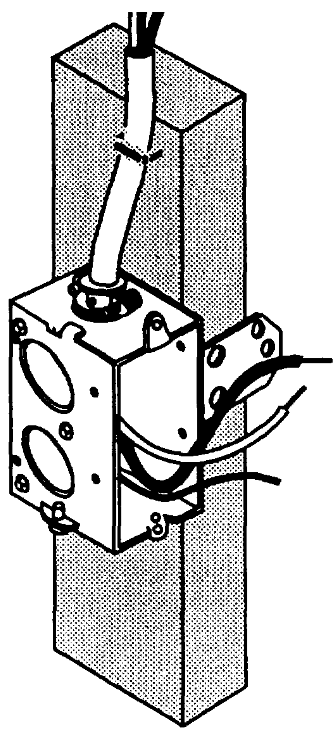


Figure 5-26.—Cable termination at box.

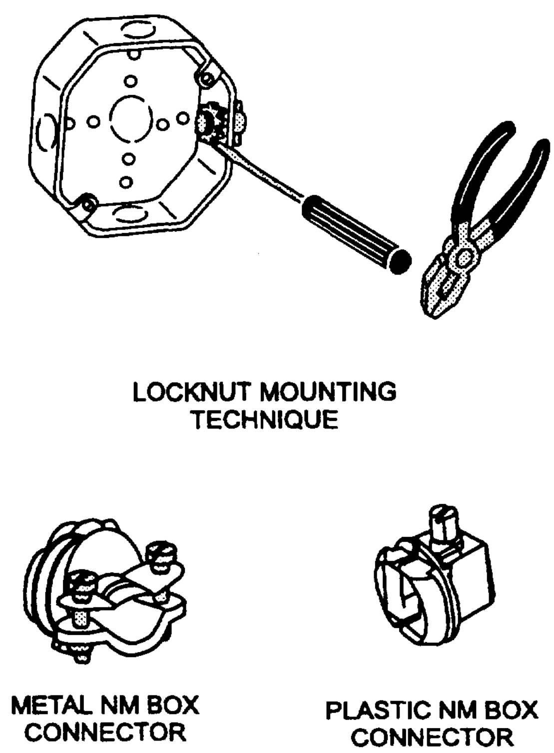


Figure 5-27.—Nonmetallic cable box connectors and mounting techniques.

Look at figure 5-28. As you can see, most of these cables are run through holes in the framing members. When holes are involved, you must plan ahead for easiest installation and the least waste. You would find it to be a little easier to run the cable between the two duplex receptacle boxes in the figure if you put a carton of cable near the box on the right and thread it through the holes to the box on the left. For the circuits that run from the left duplex receptacle box and the switch box to the ceiling outlet, the carton of cable should be placed under the boxes. Then you thread the cable up through the holes to the ceiling outlet. From these examples, you can see that you need to look at what is involved before you start to run the cable for a circuit. After you have completed the roughing-in phase of a project, your job comes to a halt for a time. In most cases, you should not start the finish work until the walls and ceilings are completed; after which you can splice wires as needed and install the receptacles, outlets, switches, lighting fixtures, and covers.

FINISH WORK

Once you begin the finish work, the first thing you need to do is to make all ground connections. Equipment grounding is the grounding of all exposed noncurrent-carrying metal parts of an electrical system to the earth. Grounding is done to protect anyone who might come in contact with these parts from being shocked and also to protect equipment from damage. Grounding is accomplished when all noncurrent-carrying parts are connected to a grounding conductor (or grounding has been achieved by other means, as approved by the NEC©), and the grounding conductor has been connected to earth at the service equipment or panelboard, as shown in figure 5-29. The equipment

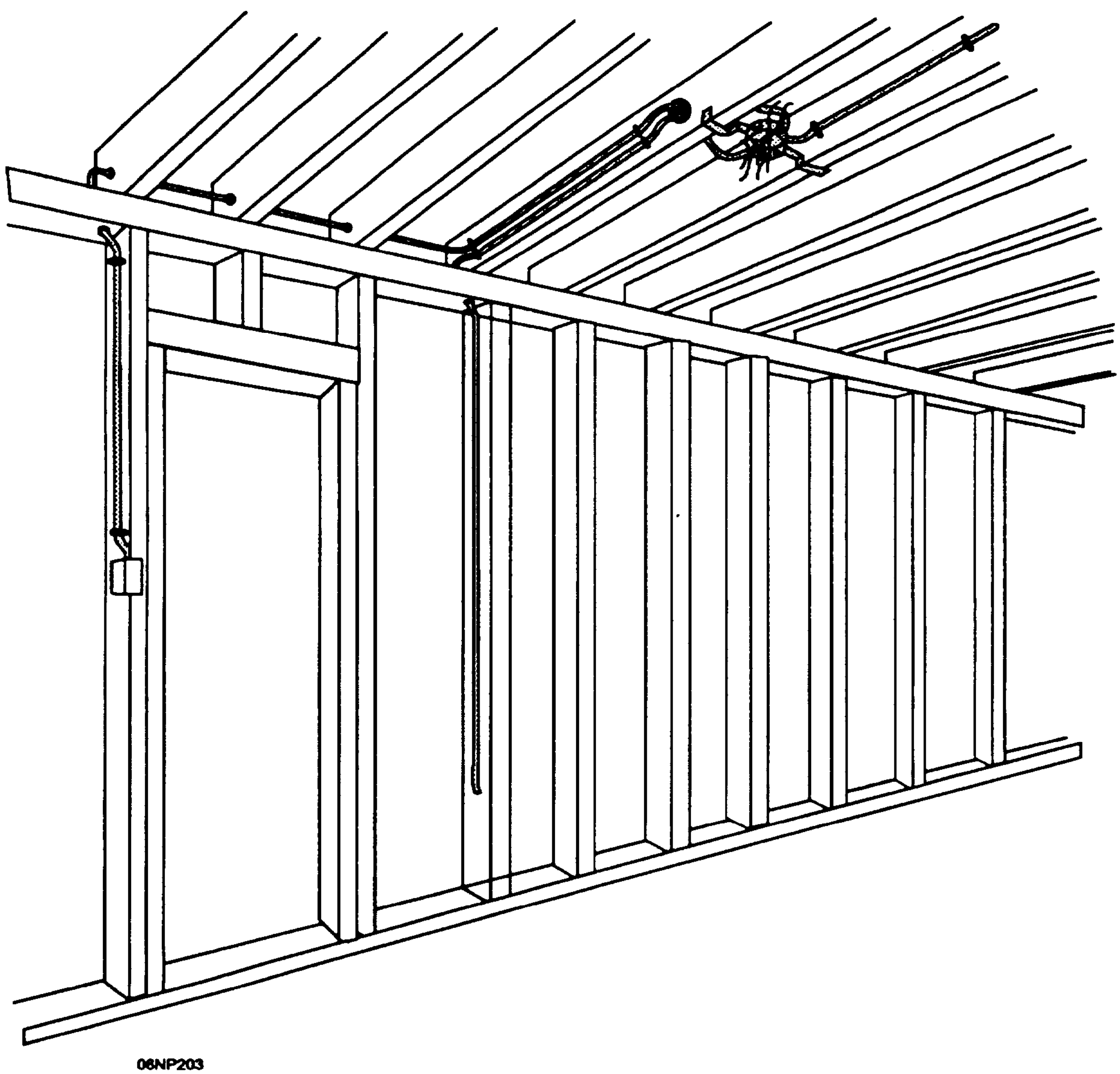
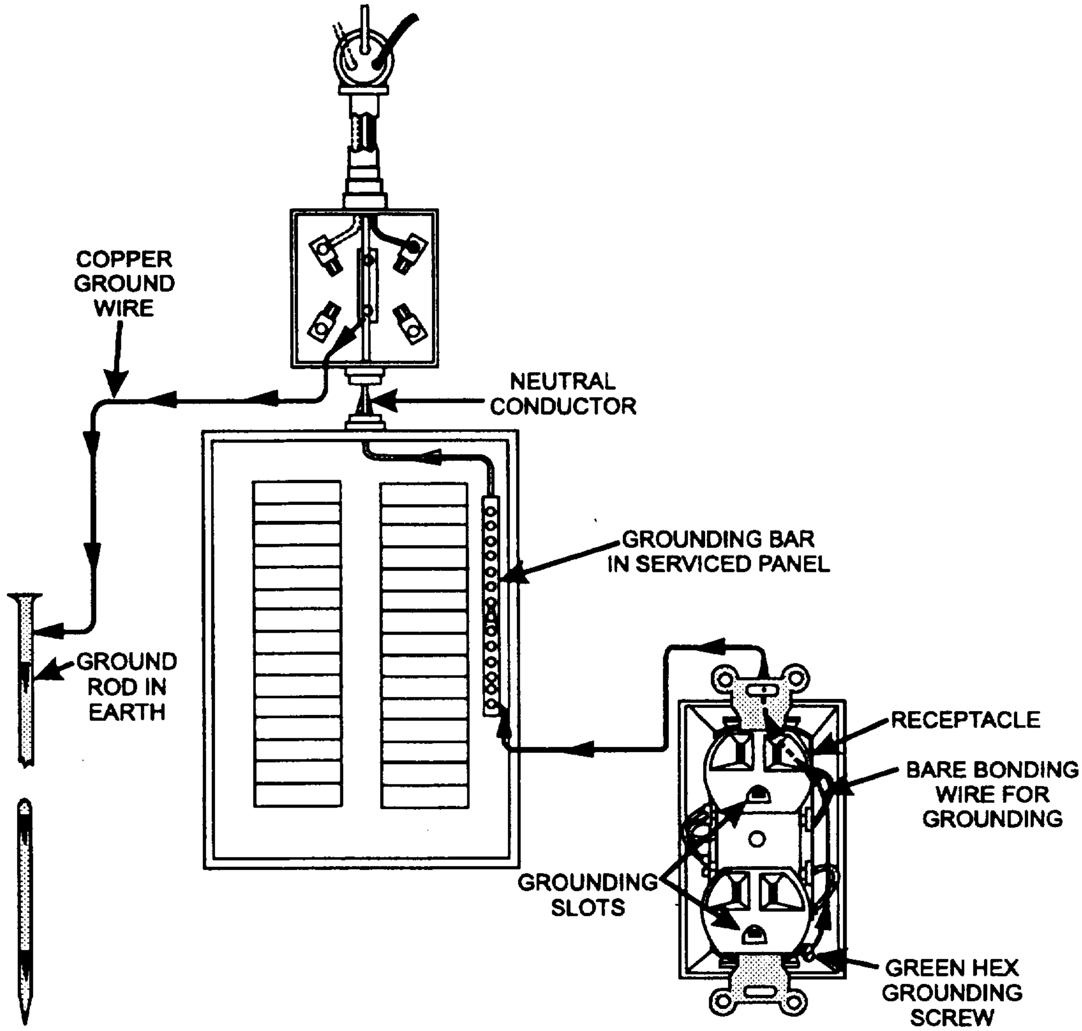


Figure 5-28.—Nonmetallic cable installation.

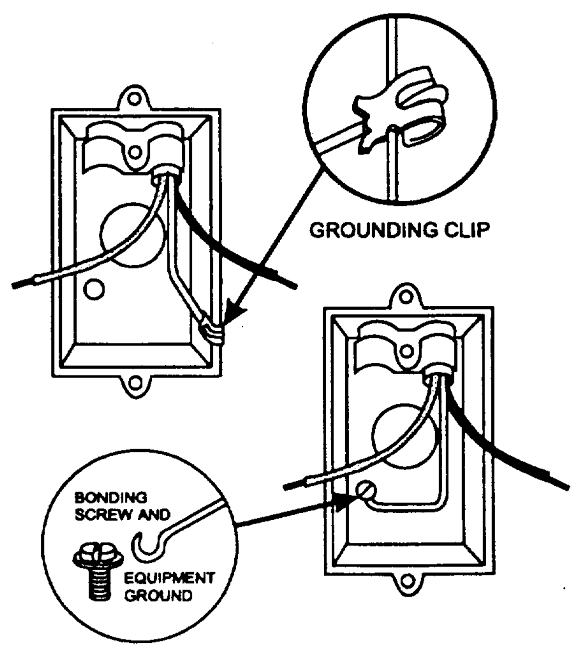


06NP0204

Figure 5-29.—Duplex receptacle electrical connection with the grounding system.

ground does not normally carry current. The only time it does is when there is a fault in the circuit. At all outlet boxes that require grounding according to the NEC©, the equipment-grounding conductor must be fastened to the box with either a grounding clip or a grounding screw, as shown in figure 5-30.

When we speak of installing a device, we should be aware that, according to the NEC©, a device is the part of an electrical system that is intended to carry, but not use, electrical energy; for example, switches and receptacles are devices. The grounded duplex receptacle comes equipped with a green hex-head screw to be used for connecting the ground wire. When more than one receptacle is connected in a circuit, the NEC© requires that these receptacles be connected to the grounding wire in such a way that the continuity of the circuit equipment ground is not broken if the receptacle is removed This grounding method is accomplished as



06NP0205

Figure 5-30.—Grounding clip and grounding screw.

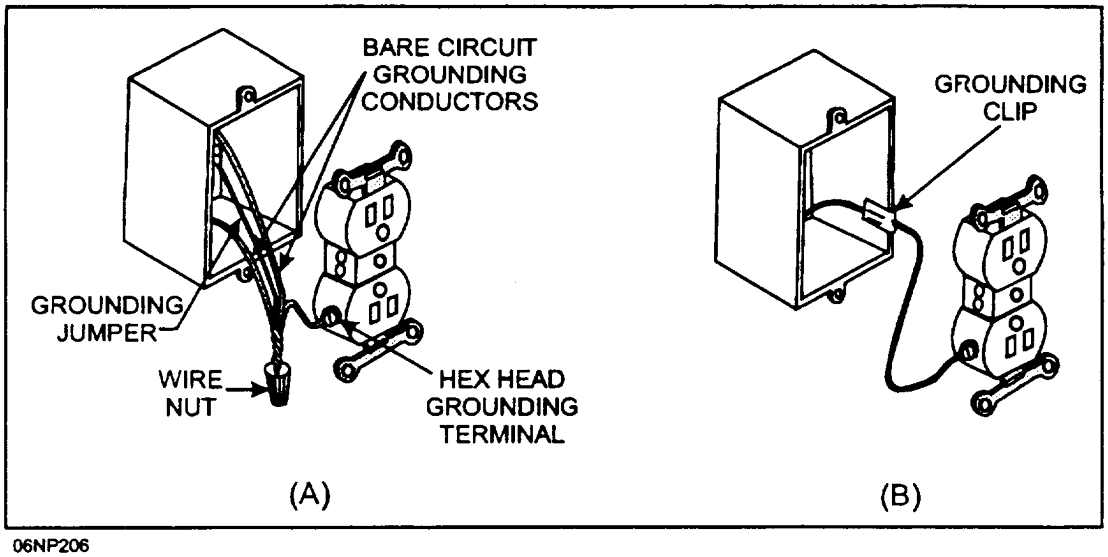


Figure 5-31.—Grounding methods: (A) More than one receptacle in line and (B) a single receptacle in a circuit.

shown in figure 5-31, view A. Figure 5-31, view B, shows an example of how you can ground a single receptacle in a circuit using a grounding clip. Grounding the receptacle in this way bonds the box, grounding wire, and receptacle, and precludes use of an additional jumper wire.

Now that we have made the ground connections, the next step of the finish work is to make terminal connections. Properly made terminal connections are important for several reasons. The operation of the circuit, prevention of tire, and safety of personnel all depend on good electrical connections. Electrical connections must be electrically and mechanically secure. There are two ways to make connections to devices: with or without using a terminal loop. The method of using the terminal loop and screw is shown in figure 5-32. Some receptacles and switches are made so that they can be wired from the back without using a terminal loop. This method is shown in figure 5-33. Now that you have made your terminal connections, you install the device into its box and secure it with the screws provided. The next step is to install the receptacle cover plates. Cover plates will be installed plumb, will completely cover the opening, and will be seated against the mounting surface.

When installing switches for interior wiring, you use single-pole, three-way, or four-way toggle switches. Most of the switches you use will be single-pole, but occasionally you will have to install a three-way system, and on rare occasions, a four-way system. Still another system of switching, called the low-voltage system, is coming into use.

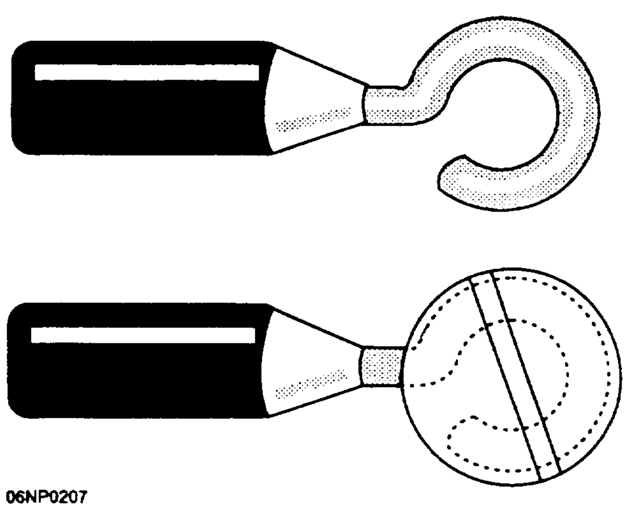


Figure 5-32.—Wire terminal loop.

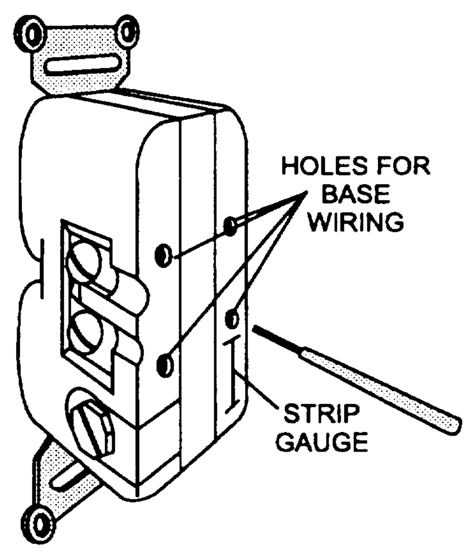


Figure 5-33.—Back-wired receptacle.

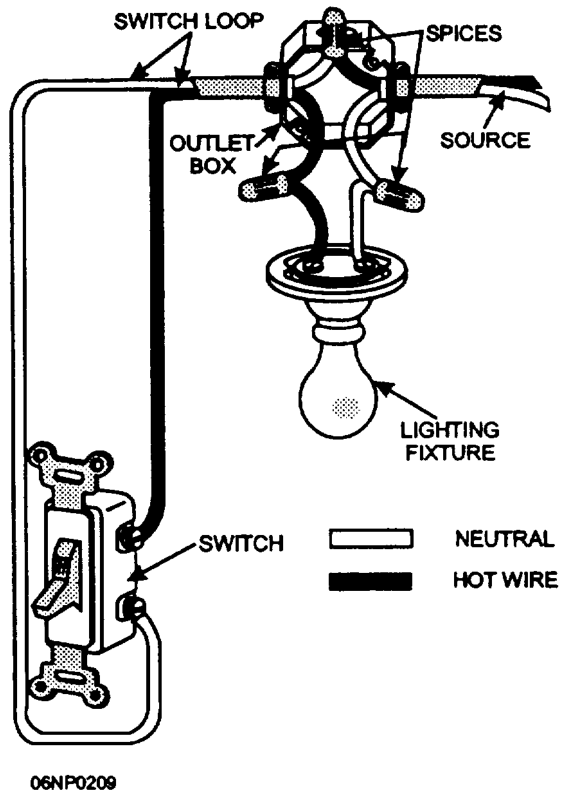


Figure 5-34.—Single-pole switch circuit.

A single-pole switch is a one-blade, on-and-off switch that may be installed singly or in multiples of two or more in the same metal box. In wiring a single-pole switch, a general rule is a neutral conductor (white wire) should not be switched or used as one leg in a switch loop. This rule is easily followed in conduit systems but does not apply to armored and nonmetallic sheathed cable. Article 200-7 of the NEC© contains the exception to this rule. Figure 5-34 shows a single-pole switch circuit using nonmetallic sheathed cable.

In a three-way switch circuit, you may turn a light on or off from either of two positions. The typical situation is one in which one switch is at the head of a stairway and the other at the foot. Figure 5-35 shows how the circuit functions.

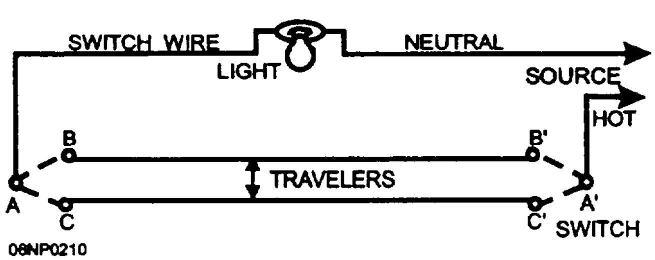


Figure 5-35.—Three-way switch circuit.

Terminals A and A' are the common terminals, and switch operation connects them either to B or C and B' or C', respectively. Either switch will operate to close or open the circuit, turning the lights on or off.

By tracing the circuit in figure 5-35 from the source, you can see that the hot wire goes to the first switch, through the closed switch blade to the other switch by way of the traveler, and through the closed switch blade to the other switch by way of the traveler, and through this switch to the light. If the position of either of the switches is changed, the circuit is broken.

One or more four-way switches may be used with two three-way switches to provide control of a lamp from three or more different points. A four-way switch is an extension of a three-way circuit by the addition of a four-way switch in series with the two traveler wires. Figure 5-36, view A, shows how a four-way switch is used in combination with two three-way switches to control a lamp from three locations. By tracing this circuit from the source, you observe the hot wire connected to Switch C passing through Position 1, which is closed. The hot wire continues to Point 4 on the four-way switch (B). At this time the toggle on Switch B is in the UP position, and contact is made from Point 4 to Point 3. The hot wire continues on through the traveler to Switch A, and through Position 2 (which is closed) to the light.

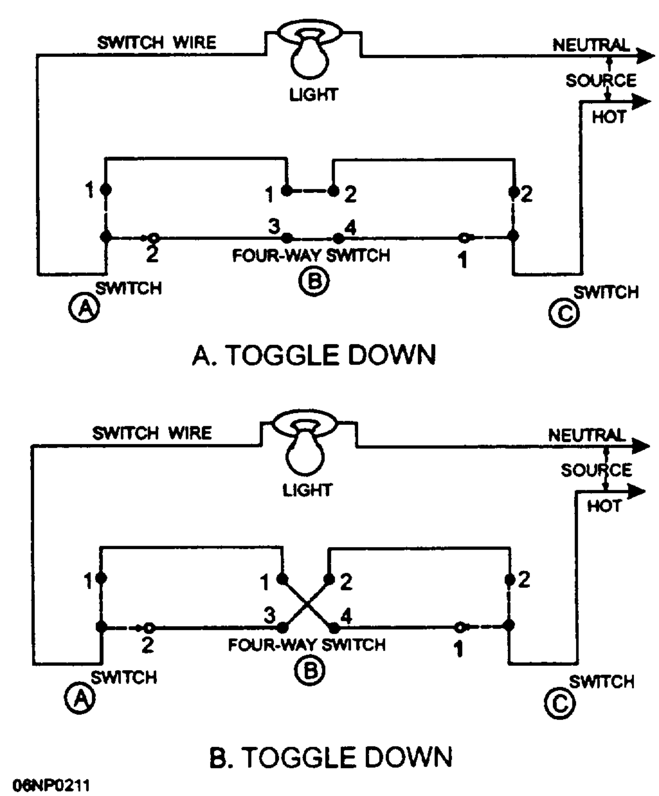


Figure 5-36.—Four-way switch circuit.

Suppose, now, that you want to turn the light off at the four-way switch (B). By putting the toggle in the OFF (down) position, you change the switch blades from Points 1 to 2 and 3 to 4 to Points 1 to 4 and 2 to 3. (See fig. 5-36, view B.) If you now retrace the circuit from Switch B to Switch A, you will find that it goes from Point 4 to Point 1 on Switch B and through the traveler to Switch A to Point 1 where the circuit is broken by the blade being in the open position.

Note that three- and four-way switches may be used as single-pole switches, and four-way switches may be used as three-way switches. However, three- and four-way switches are usually larger than single-pole switches and take up more box room. The size of a switch depends on its ampacity (rated maximum amperage). The ampacity and maximum allowable voltage are stamped on the switch and must be considered when you order equipment for the job.

REMOTE CONTROL WIRING

Remote control wiring provides a method of controlling standard voltage devices through the use of low voltage. They consists of relays, low-voltage switches, and transformers. A low-voltage conductor cable is used instead of conduit or Romex. Low-voltage wire is available as three, four, and multiple conductor cables. Multiple conductors are color coded to identify them. Roughing in a remote control wiring system uses many of the wiring techniques used with nonmetallic cables.

Remote control relays have two coils (on or off) with a common center tap. The use of two coils allows the relay plunger to be moved positively in either direction without the use of springs. When a push button (switch) is turned ON, current will pass through the ON coil and cause the movable core to shift into the ON position. The contacts are closed in the load circuit and the light goes on. The same happens when the OFF button is depressed. The current is passed through the OFF coil and the core moves. The contacts open and power to the light is turned off. The relay will maintain this position until the push button again energizes the ON coil. These relays are capable of controlling 20 amperes of lighting or inductive loads at 110 or 277 volts ac. Relays can be mounted individually in junction boxes as shown in fig, 5-37, or several may be mounted in a centrally located cabinet.

Transformers in a remote control system reduce 120-volt line voltage to 24 volts to provide power in the switching/relay circuit. Wherever transformers are located, they must be accessible and they must be kept

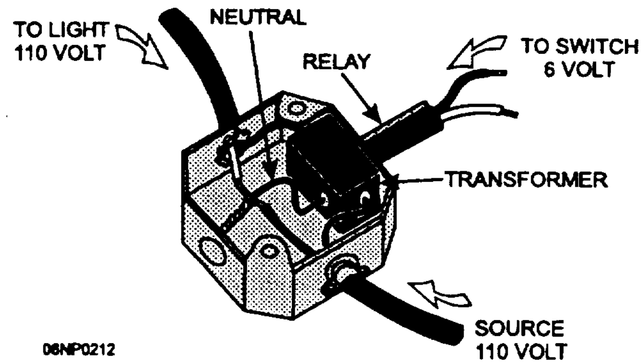


Figure 5-37.—Low-voltage relay and transformer.

from excessive heat. They are sized according to the number of relays they will power.

In the low-voltage system, as many switches as are required can be installed for any given light, or a master switch can be installed to turn on as many as eight lights simultaneously. There is no necessity for three-way or four-way switches because the switches are connected in parallel.

CONDUIT SYSTEMS

As a CE, you will be called upon to install all types of wiring systems. Unlike the electricians in civilian life who often specialize in the installation of specific types, you have to be able to install any type. In most locations you will have to install wiring systems that require the added protection provided by conduit. Conduits are of various types, such as rigid, flexible, intermediate metal, PVC, and electrical metallic tubing (thin-wall or EMT). As you read this section, you should become familiar with the different ways of bending, cutting, and threading; the fittings used; and the different locations where they may be used.

CUTTING AND THREADING

The use of rigid conduit involves a good deal of cutting and threading of lengths. It is best to cut with a hacksaw or special conduit cutter. An ordinary

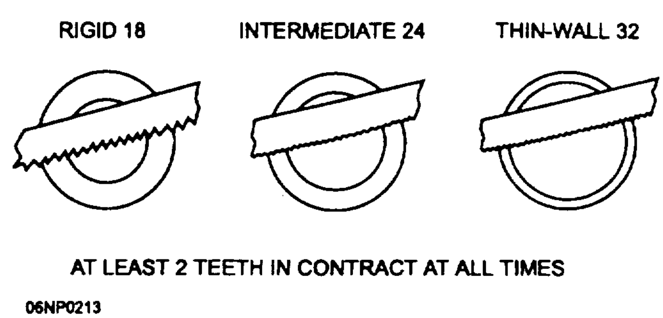


Figure 5-38.—Hacksaw blades, teeth per inch, for different types of conduit.

revolving wheel pipe cutter leaves a heavy inside ridge that is difficult to remove and may damage the passing through of conductors. Always ensure that you make a cut at right angles to the axis of the pipe (fig. 5-38).

Thin-wall conduit (EMT) and polyvinyl chloride (PVC) should be cut with a hacksaw because pipe cutters may flatten the end of the pipe. The pipe cutters also leave a ridge on the inside of the pipe that is hard to remove. There are tubing cutters made specifically for cutting EMT or PVC, but you need to be sure you have the right cutter for the job. When you are cutting conduit, use a vise to stabilize the conduit.

Flexible conduit and tubing should also be cut with a hacksaw. Because of its spiral construction, flex should be cut at an angle so that only one ribbon is cut all the way through. A slight reverse twist will separate the two ends (fig. 5-39).

Cutting any type of conduit leaves a sharp edge or burr on the inside of the pipe that must be removed by reaming. Reaming can be done with several tools. To ream rigid and intermediate conduit, you should use a pipe reamer. A rat-tailed file does a good job on any type of conduit. To ream EMT that has been cut with a hacksaw, you should use the heads of a pair of pliers, such as needle nose or side-cutting pliers, and they will do the job. The important thing is to remove any edges, or burrs, in the pipe that might cut the insulation when the conductors are pulled into the conduit.

The next step is cutting the thread on the end that was cut off. For the smaller pipe you use a ratchet type of die that turns directly with the handle. On larger pipe you use a die with a mechanical advantage; that is, you use a die that makes only a part of a revolution when the handle makes a complete revolution. Hand-held portable electric and shop type of threading machines are also available.

A conduit-threading die, like a plumber's die, makes a tapered thread, so that a coupling starts rather

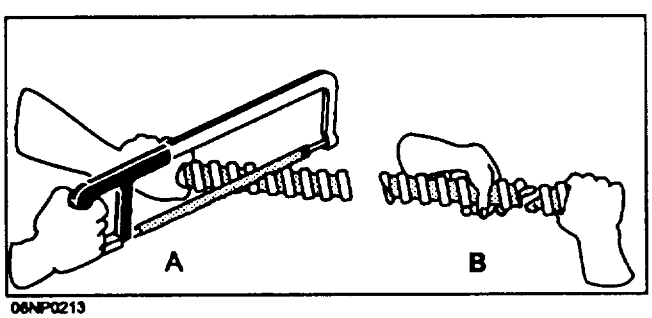


Figure 5-39.—Cutting flexible conduit.

loosely but binds hard as it is set up. This tight connection serves two purposes: it makes a watertight joint and it makes a good electrical connection for a continuous ground throughout the length of the conduit.

Rigid polyvinyl chloride (PVC) conduit has been developed by many manufacturers. Some of the advantages of PVC conduit are the light handling weight, high corrosion resistance, ease of installation, leakproof joints, and easy wire pulling (because of the mirror-like walls). Refer to Article 347 of the NEC© for installation requirements.

Permanent joints are made quickly in PVC conduit by cutting the conduit with a handsaw or hacksaw and removing the burrs with a pocketknife. When joining PVC conduit, always follow the manufacturers' instructions listed on the cement can for best results. A variety of threaded PVC fittings are available from manufacturers. Their use is covered in Article 370 of the NEC©. The preferred method of installation is by the solvent-welding technique because the joints are waterproof and vapor-proof.

CONDUIT BENDING

The NEC© Article 346 through 348 applies to electrical conduits. It states that the "bends in conduits will be made so that the tubing will not be injured and that the internal diameter of the conduit will not be effectively reduced." In addition, the NEC© has a table that indicates the minimum radius acceptable for various sizes of conduit. It also states that "a run of electrical conduit between outlet and outlet, between fitting and fitting, or between outlet and fitting, will not contain more than the equivalent of 4 quarter bends (360 degrees total) including those bends located immediately at the outlet or fitting."

When installing conduit, you will need to make bends to go over or around obstacles. Bends of various shapes will be needed, such as right-angle or 90-degree bends, offsets, and saddles. These bends must be made without reducing the inside diameter of the conduit in the bend. You will make most of these bends on the job as part of the installation procedure. They are called field bends. Factory-made bends may be used instead of field bends; however, they will cause you more cutting and threading, and they increase the cost of the job.

Most of the field bends will be done with manual benders or a hot box heater in the case of rigid nonmetallic conduit. Manual benders used to bend rigid conduit and EMT are of two types. These are the rigid bender, called a hickey (fig. 5-40), and the one-shot bender (fig. 5-41). The one-shot bender is normally made for EMT, but some are made to be used for both EMT and rigid. The one-shot bender was given this name because a full 90-degree bend can be made with a single motion. Conduit sizes up to 1-inch rigid or 1 1/4-inch EMT can be bent without much trouble with manual benders. Larger sizes are bent with mechanical or hydraulic benders. Hydraulic benders will be discussed at the second-class level.

Rigid Nonmetallic Conduit

Although a complete line of factory elbows (90, 45, or 30 degree) are available, bending PVC conduit (1/2 through 2 inch) is accomplished easily with the use of a PVC hot box. A PVC hot box is nothing more than a heater, enclosed by metal having a mirror finish on the inside with openings on each end. To bend PVC conduit, place the conduit inside the hot box, turn the switch on, rotate the conduit until it becomes flexible, remove the conduit, and bend it to the desired shape.

WARNING

The hot box is a heater. If you leave the conduit in long enough, it will BURN. You should use gloves when bending PVC.

Electrical Metallic Tubing (EMT)

Conduit bending is a precise art form. You will use degrees, angles, measurements and prefigured deductions for radiuses and shrinkage. Combine all these calculations correctly and you will get a finished product that is not only functional but pleasing to the eye, and something to be proud of.

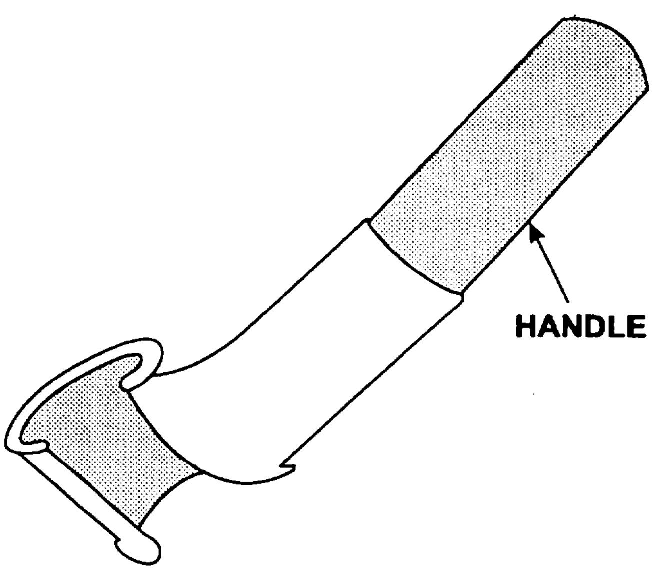


Figure 5-40.—Hickey.

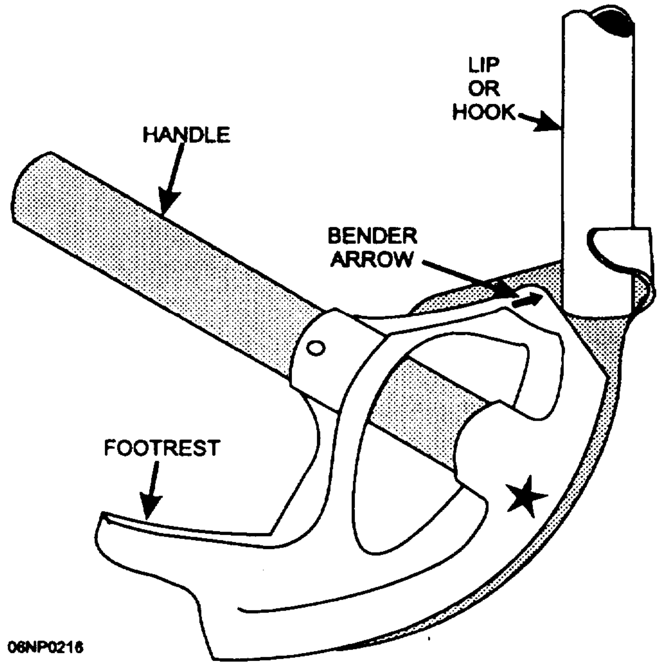


Figure 5-41.—One-shot hender.

90 DEGREE BENDS.—One of the most common bends you will make in the field is the right-angle bend, more commonly called a 90-degree bend, or just a 90. Anyone can make a 90 in a stick of conduit and then cut it off to make it fit the situation, but this practice wastes time and material. The secret is to bend the conduit in the right place so that you do not have to cut it. To accomplish this, there are some things you have to know. First, you need to know the distance from the end of the conduit to the back of the 90. This distance is called the stub-up. Second, the radius of the bend takes up a part of the stub-up. This part is called the take-up. The amount of take-up depends on the type and size of conduit you are bending. (See table 5-2.)

Table 5-2.—Conduit Take-up

AMOUNT OF TAKE-UP FOR 90° BENDS (ONE-shot Benders)	
SIZE AND TYPE OF CONDUIT	TAKE-UP
1/2" EMT	5"
3/4" EMT OR 1/2" RIGID*	6"
1" EMT OR 3/4 RIGID*	8"
1 1/4" EMT OR 1" RIGID*	11"
*IMC AND RIGID WILL BE THE SAME	

06NP0217

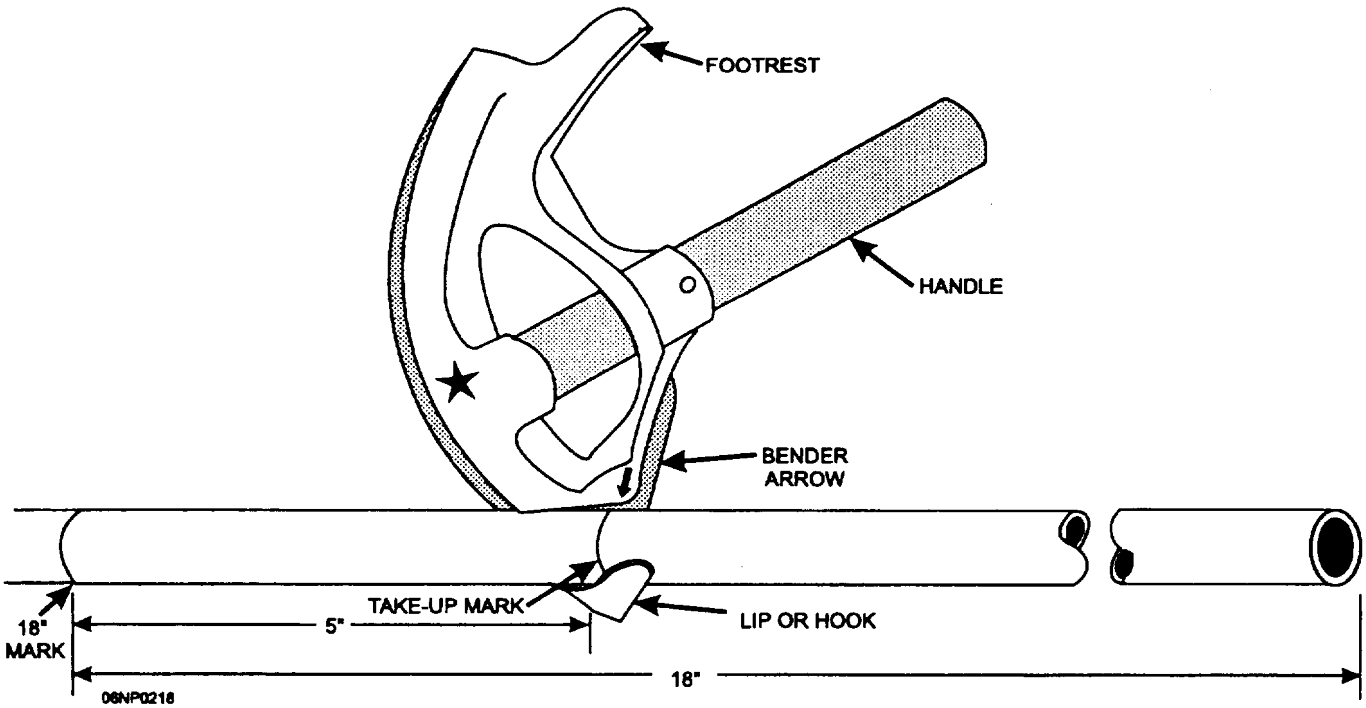


Figure 5-42.—Alignment of arrow and take-up mark for bending a 90.

Now, let us see how a 90 is made to fit a specific situation. Suppose you are going to run the conduit from the top of a panel to the ceiling and then horizontally along the ceiling, using 1/2-inch EMT and a one-shot bender. The first step will be to measure from the top of the panel to the ceiling. This measurement will give you the stub length. Assume the length is 18 inches. Measure 18 inches from the end of the conduit and make a mark at that point. Next, look at table 5-2 and find the take-up for 1/2-inch EMT. The take-up is 5 inches. Now, measure 5 inches back toward the end of the conduit from your first mark and make a second mark. This measurement gives you the take-up. Place the conduit on the floor with the stub in front of you. Align the bender arrow with the take-up mark, as shown in figure 5-42. Put one foot on the footrest and hold the handle with both hands. Apply pressure on the footrest as you pull the handle until the handle is at about a 30-degree angle with the floor, as shown in figure 5-43. You should now have a 90-degree bend with an 18-inch stub. Remember: Heavy foot pressure is critical to keep the EMT in the bender groove and prevent kinked conduit. To check that the bend will fit the situation we started with, you can place it next to anything that you know is a right angle and measure from the floor to the end of the stub. If the bend is not a full 90, place the bender back on the conduit, and pull more bend. If it is more than a 90, place the handle of the bender over the end of the stub, place one foot on the conduit on the floor, and spring the stub back.

BACK-TO-BACK BENDS.—The back-to-back bend is actually two adjacent 90s made in the same piece of conduit. You make the first 90 with the amount

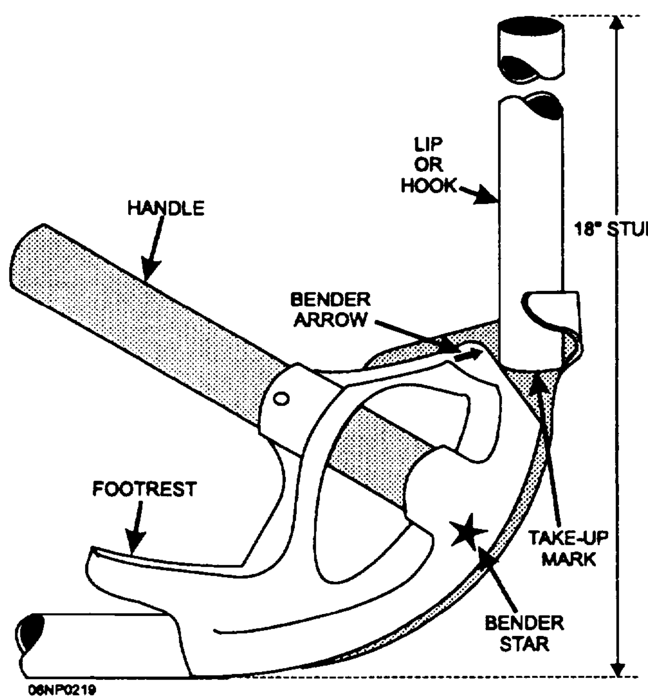
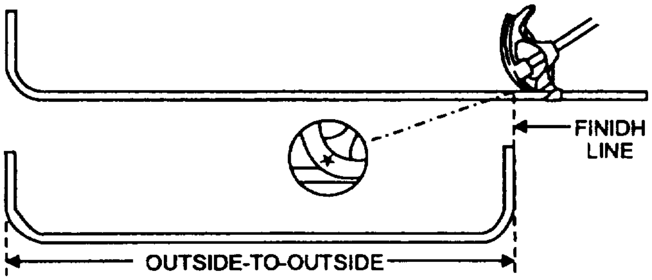
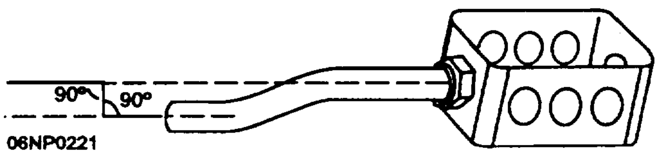


Figure 5-43.—Right-angle bend, 90.



06NP0220

Figure 5-44.—Using the star for back-to-back bend.



06NP0221

Figure 5-45.—Box offset.

of stub you need, as described previously. To determine where to place the next stub, you first need an outside-to-outside measurement. This measurement is the distance from the back of the first bend to the point where you want the back of the second bend.

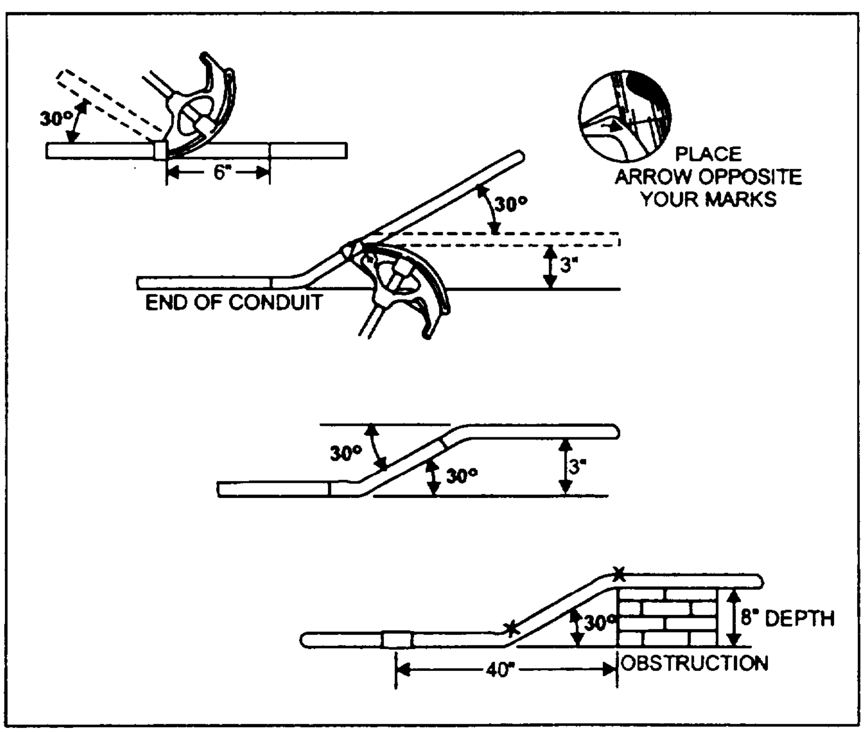
Two methods are used for making the second bend. The first is to subtract the take-up, use the arrow on the bender, and pull the bend in the same direction as you did the first bend. The second method, and probably the easiest, is to turn the bender around, line up the star on the bender with your outside-to-outside measurement, and pull the bend in the opposite direction, as shown in figure 5-44.

Table 5-3.—Offset Bending Formula

FORMULAAND CONSTANT MULTIPLIER FOR DETERMINING DISTANCE BETWEEN BENDS WHEN BENDING OFFSETS		
FORMULA **OFFSET DEPTH x CONSTANT MULTIPLIER = DISTANCE BETWEEN BENDS**		
ANGLE OF BENDS	CONSTANT MULTIPLIER	SHRINKAGE
22 1/2°x 22 1/2°	2.6	3/16” PER INCH
30° x 30°	2.0	1/4” PER INCH
45° x 45°	1.5	3/8" PER INCH
60° x 60°	1.2	1/2” PER INCH

06NP0222

OFFSET BENDS.—An offset bend is two equal bends in opposite directions. It is used to avoid contacting a part of the structure or to bring the conduit out from the structure to match a knockout in a box or panel. The angle of the bend in an offset depends on several things; how much offset is needed, how much room there is where the offset is going to be placed, and the type of obstacle you are avoiding. Figure 5-45 shows a box offset into a handy box. There is no way to mark the conduit for a box offset. The amount of bend and the distance between bends are estimated. The key to making good box offsets is practice.



06PN0223

Figure 5-46.—Bending an offset.

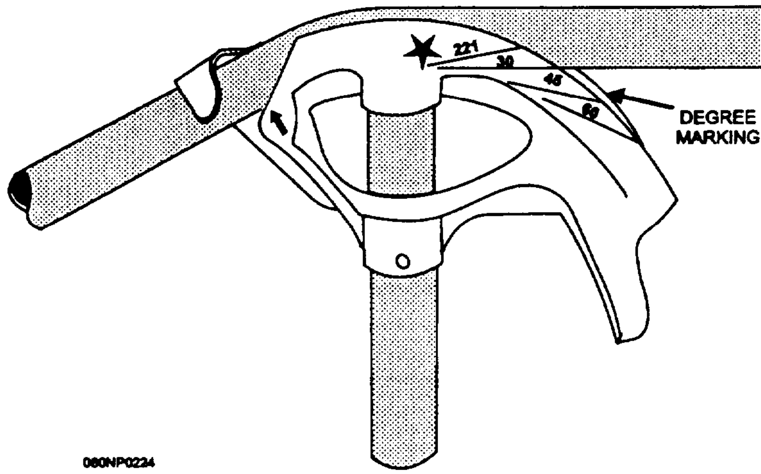


Figure 5-47.—Bender degree markings.

To make accurate offsets of 2 inches or more in depth, you can mark a predetermined distance on the conduit. The distance between the bends depends on the depth of the offset and the amount of bend that you are going to use. Table 5-3 shows the formula to use to find the distance to be marked on the conduit. It also shows the constant multiplier that must be used in the formula for the angle of bends you intend to use and the shrinkage per inch.

Let us use an example to see how the formula works. Suppose you need to avoid a part of a obstruction that requires an 8-inch offset, you are going to use 30-degree bends, and you are 40 inches from the obstruction. Table 5-3 shows that the constant multiplier for 30-degree bends is 2 and the shrinkage of one-fourth inch equals 2 inches for a total of 42 inches. Using the formula, multiply the depth of the offset (8 inches) times the constant multiplier (2), and the result is the distance needed between the bends (16 inches). You place the first mark at 42 inches, the second 16 inches apart, and using the arrow of the bender, make a 30-degree bend on the same side of each mark, as shown in figure 5-46. In this example, a 30-degree bend gives us the offset we need. If you make both bends inside the marks, you will end up with much less than the desired offset. If you make both bends outside the marks, you will have too much offset. The amount of bend, in this case 30-degree at each mark, is obtained by using the degree markings on the bender, as shown in figure 5-47. Notice that the side of the conduit closest to the bender is in line with the 30-degree marking on the bender. If you have a bender without markings, a protractor (works especially well on larger conduit) can be used or you can lay a 30-degree angle out on a large piece of paper or on the floor with chalk. Then check the bend against the 30-degree angle you have laid out. Normally, offsets are made by making the first bend on the floor and the second bend in the air, as shown in figure 5-48.

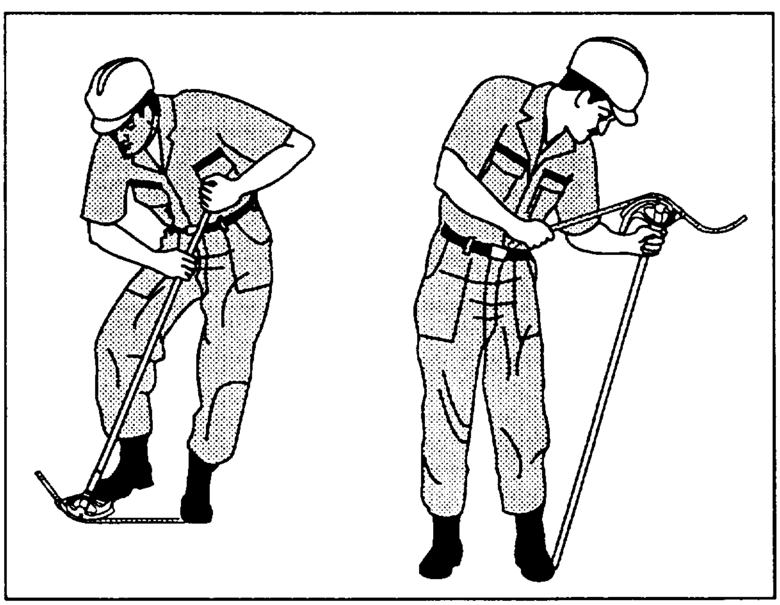


Figure 5-48.—Bending on the floor and in the air.

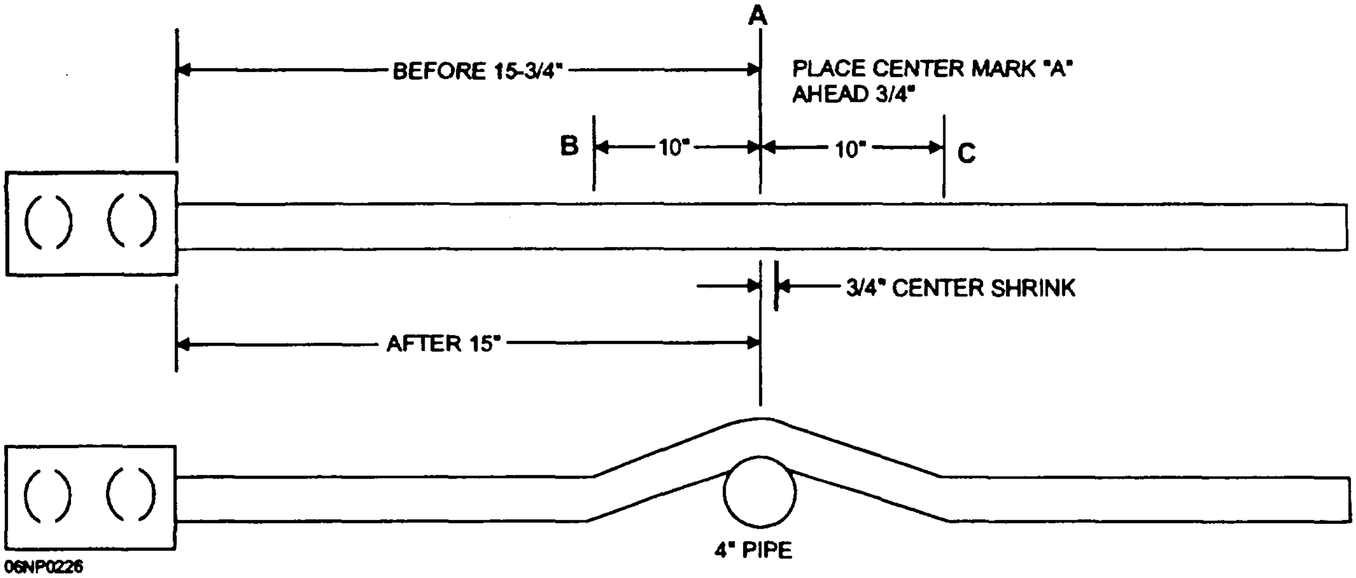


Figure 5-49.—Bending a conduit saddle bend.

SADDLE BENDS.—Saddles may be necessary when obstructions (fig. 5-49) are encountered. The most common method of straddling an obstacle is the three-bend saddle, using a 45-degree center bend and two opposing 22 1/2-degree bends. All measurements begin with locating the center of the obstruction on the conduit and marking it as Point A. Table 5-4 shows shrinkage factors and distances for marks "B" and "C." The formula is from mark “A,” add 3/16 of an inch times saddle depth and distance from mark “A” to marks "B" and "C" = 2.5 inches times saddle depth.

Figure 5-49 is an example of placing a 4-inch saddle around a conduit that is 15 inches from a junction box. Following the bending sequence shown, pay close attention to the orientation of the bender head. Remember to use the star arrow on the bender to align Point A for the 45-degree center bend and the front arrow to align the bender with marks "B" and "C" for the 22 1/2-degree bends. Be sure to line up all bends in the same plane. This procedure is true of all bends, not just a saddle.

Table 5-4.—Bending Conduit Saddle Table, Shrinkage Factors, and Distances

BENDING CONDUIT SADDLE TABLE, SHRINKAGE FACTORS, AND DISTANCES		
SADDLE DEPTH	PLACE CENTER MARK "A" AHEAD OF ACTUAL CENTER BY	PLACE MARKS "B" AND "C" EACH WAY FROM CENTER
1"	3/6"	2-1/2"
2"	3/8"	5"
3"	9/16"	7-1/2"
4"	3/4"	10"
5"	15/16"	12-1/2”
6"	1-1/8"	15"
FOR EACH ADDITIONAL INCH ADD	3/16"	2-1/2"

06NP0227

Rigid Metal Conduit

The procedures for making the different types of bends discussed thus far have all been with a one-shot bender. The same bends can be made with rigid conduit. Ahickey bender can be used on rigid metal conduit also although the procedures are slightly different. For instance, to make a 90-degree bend in 1/2-inch rigid metal conduit, you should take the steps shown in figure 5-50. Let us say you need a 20-inch stub-up at the end of the 1/2-inch stick of rigid conduit. The steps for bending with a hickey are as follows:

1. Mark off 20 inches from the end of the conduit.
2. Determine the take-up for 1/2-inch rigid conduit. (See table 5-2.)
3. Make a second mark 6 inches back toward the end of the conduit.
4. Place the hickey at the second mark and pull about 30 degrees of bend.
5. Move the bender toward the 20-inch mark about 2 inches. Pull another 30 degrees of bend.
6. Move the bender to where the heel of the bender is on the 20-inch mark and complete the 90-degree bend.

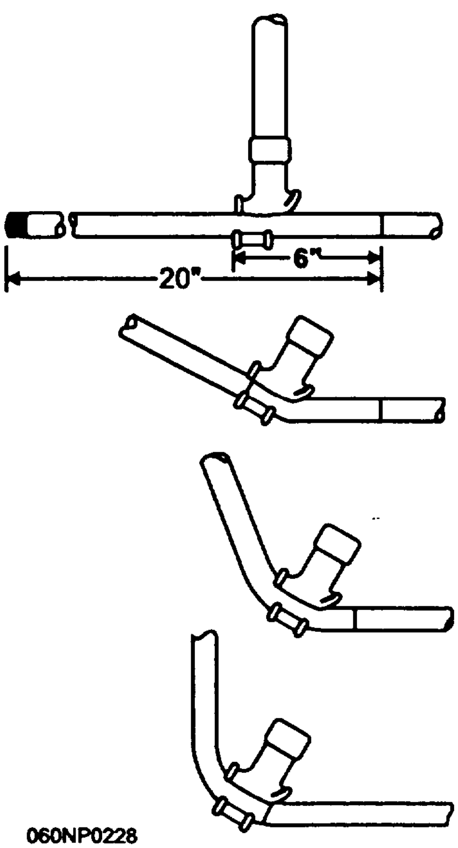


Figure 5-50.—Bending a 90 with a hickey.

Since the hickey bender does not usually have degree markings on it, you have to estimate the amount of bend you are making with each bite. Small bites, as shown in figure 5-51, reduce the possibility of crimping or kinking the conduit.

Mechanical Benders

Mechanical benders are designed to bend conduits using a built-in ratchet for fast, no kink, bends. Depending on the make and model, they are portable and easy to use. Equipped with different shoe sizes, they will bend EMT conduit from 3/4 inch through 2 inch, rigid and aluminum conduit 1/2 through 1 1/2 and IMC 1/2 through 1 1/4. Minimum stub lengths and take-up deductible inches vary from the hand benders just discussed. While the bending principles are the same, you will need to check with the manufacturers directions and bending charts.

CONDUIT INSTALLATION

In previous sections we have discussed types of conduits and the cutting, threading, and bending of conduit. Now, we will cover the requirements for installing the different types of conduit and how conductors should be pulled into them.

Several general requirements apply to all types of conduit installation: All raceways must be installed as a complete system before any conductors are pulled into them. In other words, the "run" of conduit, as described previously, including conduit, fitting, and supports, must be complete before the conductors are installed. A run of conduit should be as straight and direct as possible. When a number of conduit runs are to be installed parallel and adjacent to each other, you should install them all at the same time. The minimum-sized raceway that can be installed generally is 1/2-inch electrical trade size. Specific exceptions to this rule

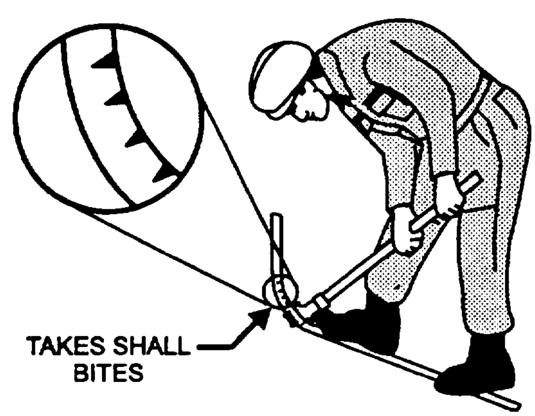


Figure 5-51.—Bending with a hickey using small bites.

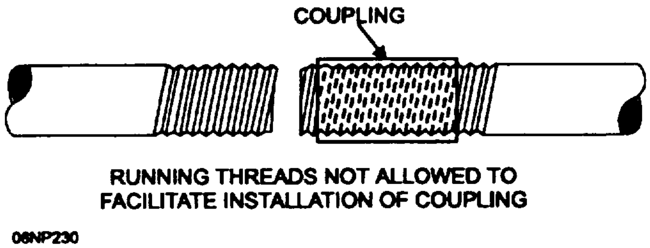


Figure 5-52.—Running threads.

include EMT, rigid, and flexible conduit installed in specific locations. The exceptions for each type are outlined in the NEC©. All types of conduit must be reamed after they have been cut. Conduit threaded in the field must be threaded with a die that has a 3/4-inch taper per foot. When threaded conduit enters a box or fitting, a bushing must be used to protect the conductor insulation from being cut or tom. Also, for those types that use threaded couplings, running threads, as shown in figure 5-52, are not to be used for connection at couplings. Running threads weaken the conduit and may come loose. Threaded couplings and connectors used with any type of conduit must be made up tight. Couplings or connectors that are to be buried in concrete or masonry have to be the concrete-tight type; those to be installed in wet locations have to be the raintight type.

Conduit must be supported by straps or hangers throughout the entire run. Figure 5-53 shows how straps are fastened on different types of surfaces. On a wooden surface, nails or wood screws can be used to secure the straps. On brick or concrete surfaces, first you just make a hole with a star or carbide drill and then install an expansion anchor. Use an expansion tool to force the anchors apart, forming a wedge to hold the anchor in the hole. Then secure the strap to the surface with machine screws attached to the anchor. On tile or other hollow material, secure the straps with toggle bolts. If the installation is made on metal surfaces, you can drill holes to secure straps or hangers with machine or sheet metal screws.

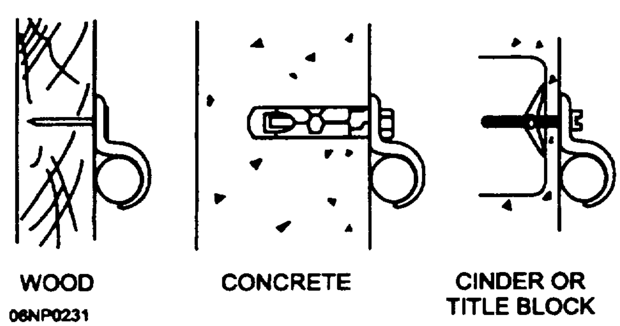


Figure 5-53.—Conduit support fastening.

Table 5-5.—Nonmetallic Conduit Support

CONDUIT (Inches)	MAXIUM SPACE BETWEEN SUPPORTS (Feet))
1/2 -1.........	3
1 1/4 - 2......	5
2 1/2 - 3.......	6
3 1/2 - 5......	7
6	6

06NP0232

The number of supports needed depends on the type of conduit being used. Holes, or notches, in framing members may serve as supports. EMT and IMC require supports within 3 feet of each outlet box, junction box, cabinet, or fitting, and every 10 feet thereafter. Rigid metal conduit must also be supported within 3 feet of a box, but the distance between supports may be increased as the size of the conduit increases if the run is straight and is made up with threaded couplings. The distance between supports on direct vertical runs of rigid conduit from machine tools, and the like, may be increased to 20 feet if threaded couplings are used and the riser is supported at each end.

Rigid nonmetallic conduit must be supported, as shown in table 5-5. In addition, it must be supported within 3 feet of each opening.

Flexible metal conduit and liquidtight flex must be supported at intervals not to exceed 4 1/2 feet and within 12 inches on each side of every outlet box or fitting. Exceptions to this rule are runs of 3 feet or less where flexibility is needed or 6 feet where light fixtures are being connected.

When you run conduit from one point to another, you often need to make more turns than the NEC© allows in a single run (360° of bends). When this larger number of turns is the case, you can use a fitting called a conduit body. Conduit bodies are often referred to by their brand names, such as Condulet or Unilet. A conduit body is a portion of a conduit system that provides access to the system through a removable cover to the interior of that system at a junction of two or more sections or at a terminal point. An important point to remember is that all Condulets must be accessible after construction is completed. Figure 5-54 shows some of the more common conduit bodies and covers.

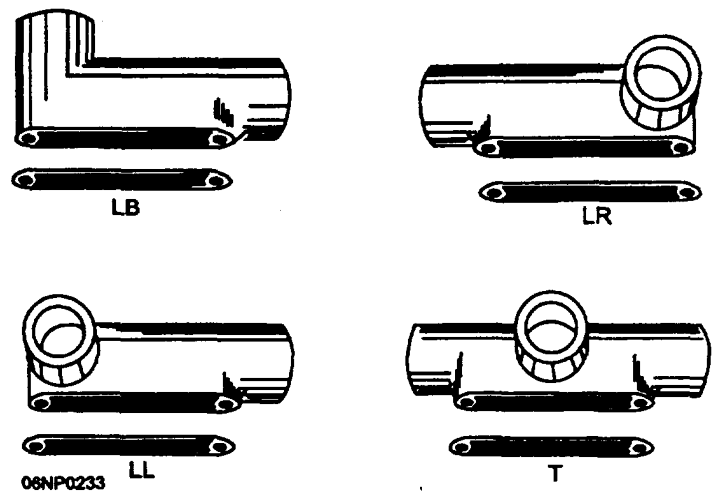


Figure 5-54.—Conduit bodies and covers.

Figure 5-55 shows how a conduit body is put in conduit between two outlets to keep the bends within NEC© limits for a single run. As you can see, the run on the left has bends that total 360 degrees, which is all the NEC© permits. Thus a conduit body, as discussed in NEC© Article 300, had to be installed so that the conduit could be continued to the box on the right. After all conduit has been installed, supported, and connected to the boxes, you are ready to install the wire.

Conductor installation into conduits is the same for all types of conduit. The most common type of wire used is TW. This letter designation simply means that the wire or conductor has thermoplastic, moisture-resistant insulation. When you are determining the length of wire needed to be pulled into the circuit, simply add the following: (1) lengths of conduit, (2) the size and number of boxes you must pull through, (3) the length of wire needed at each box, and (4) the makeup for the distribution panel.

For short conduit runs with only two wires, the conductors can be pushed through the conduit from one box to the next. When the conduit has several bends and more than two conductors will be installed, a fish tape has to be used to pull the wires through the conduit. The fish tape normally has a hook on one end, which is pushed through the conduit. The hook also makes it easier to push the tape through. If the hook is broken off, you can make a new one with a pair of pliers and a propane torch. The torch is used to heat the end of the tape to take out the temper. On a l/S-inch tape, heat

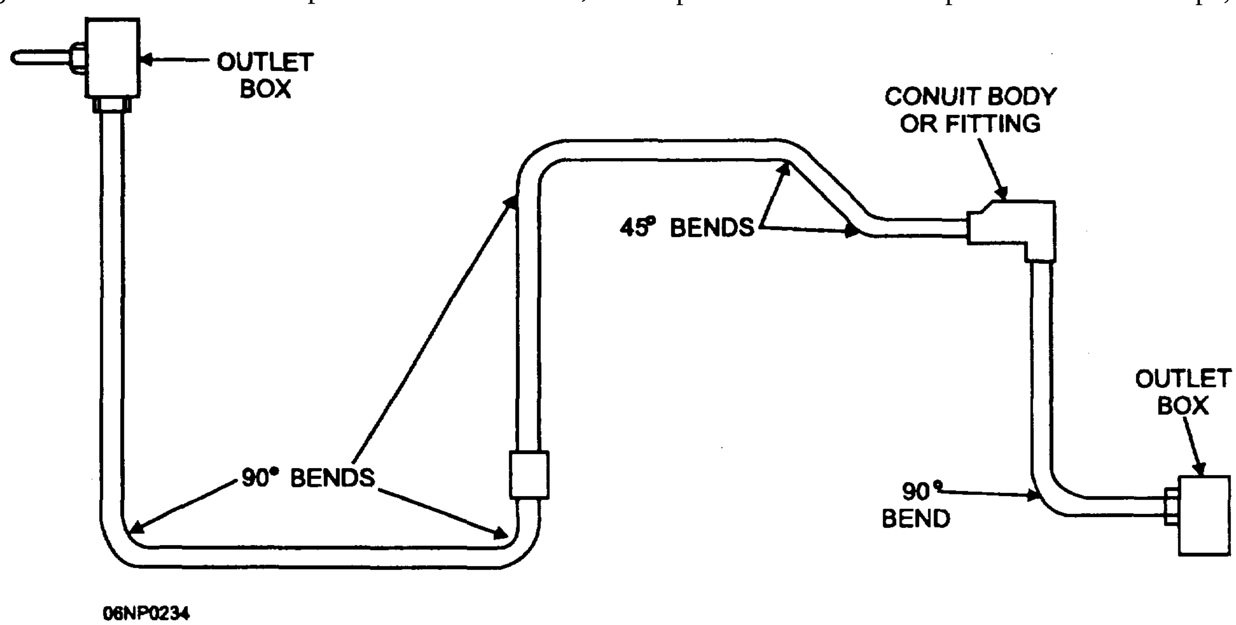
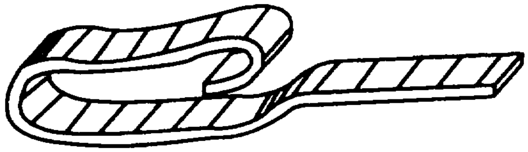


Figure 5-55.—Conduit body installed.



06NP0235

Figure 5-56.—Fish-tape hook.

about 3 inches at the end of the tape until it is red-hot, and bend a hook on it about an inch long, like that shown in figure 5-56. This shape of hook seems to work best. After the hook is formed, reheat the end of the tape until it is red. Allow the end to cool until it becomes straw-colored. Then plunge it into a can of water until it is cool. This process restores the temper to the hook area.

Once you have the fish tape in the conduit, attach the hook to the wires to be pulled, as shown in figure 5-57. Remove 4 to 6 inches of the insulation from the ends of the wires and thread the ends through the hook in opposite directions; bend them back and twist them around each other; then tape the hook and bare conductors to strengthen the attachment and make pulling easier. Use just enough tape to cover the hook and wires.

Wire pulling usually takes two people-one to pull the fish tape and the other to feed the conductors into the conduit. The fish tape should be fed into the end of the conduit run from which it will be easiest to pull. It is usually best to pull the conductors from the distribution panel to the first box in the run, especially if the panel is energized. This procedure prevents your having to pull on the steel tape near an energized bus.

WARNING

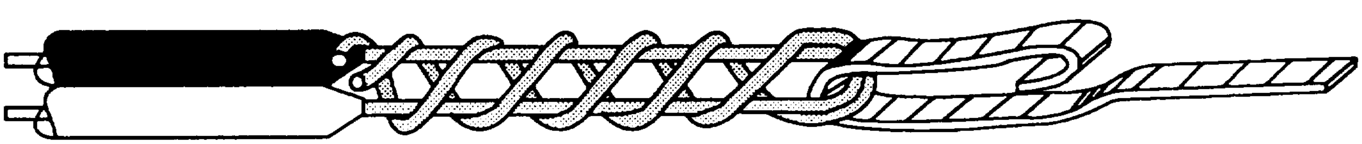
Whenever conductors are being pulled into energized panels, be careful to keep clear of the bus bars. All energized parts should be covered with a rubber blanket.

When several conductors must be fed into a conduit, you should keep them parallel, straight, and free from kinks and bends. Wires that are allowed to cross each other form a bulge and are hard to pull around bends. Whenever possible, feed conductors downward; for example, from the second floor to the first, so the weight of the wires will help in the pulling process. Another way to ease the pulling of conductors is to rub an approved lubricant, such as soap, talc, soapstone, or other noncorrosive substance, onto the insulation or blow it into the conduit. You may find that it is hard to keep the fish tape from slipping in your hands when you are pulling long runs or runs with several bends. When slipping is a problem, you can use the back side (insulation crushing point) of a pair of side-cutting pliers to grip the tape to give you a good pulling handle.

Remember to leave at least 6 inches of free conductor at each outlet and switch box to make up splices or to connect devices. Conductors that are not spliced or connected to a device can be pulled directly through the box.

The number of conductors you can have in conduit is based on the size of the conduit, the type of conductor insulation, and the size of the conductors. The NEC©, chapter 9, has several tables to help you determine how many conductors of a certain size and insulation type you can have in a given size of conduit. These tables are based on fill; that is, the cross-sectional area of the conductors inside the conduit can take up only a certain percentage of the free space inside the conduit. You must use these tables whenever there is a question on the number of conductors to be pulled. Too many conductors in a conduit cause overheating, which reduces conductor ampacity.

Once you have installed the conductors and all other finish work is complete, you are ready to do the electrical finish part. Finish work for conduit installations is the same as that for NM cable installations, which was covered previously in this chapter.



06NP0236

Figure 5-57.—Wires attached to fish tape.

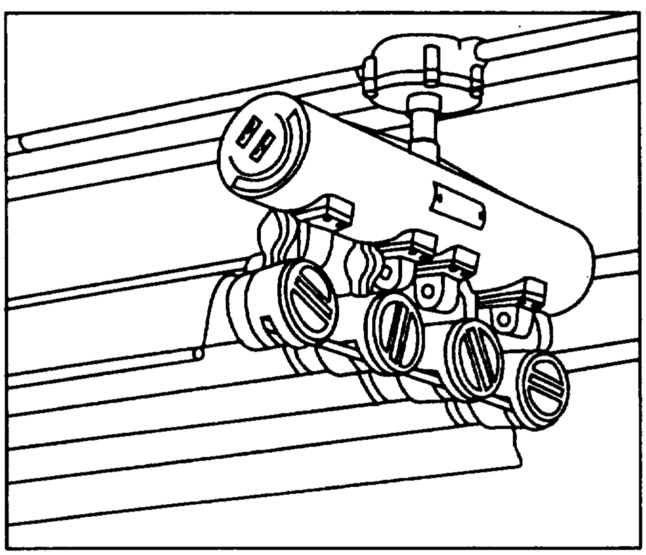
Explosion Proof Fittings

In locations specified by the NEC© (Articles 510 through 517) as explosion-hazardous, you must install explosionproof fittings. Locations are classed by number in descending order of danger: Class 1, Division 1, highly hazardous; Class 1, Division 2, slightly less hazardous; and so on.

As an example of explosionproofing, in a gasoline filling station, the pump island is classed as Class 1, Division 1. All the conduits in this area must be sealed with a special sealing fitting. On conduit for lights above the pumps, the sealing fitting must be located at a height of not less than 4 feet above the driveway surface. No junction boxes (explained in the NEC©) or Condulets may be used in the pump area. Conduits running from pumps to panels in the building must be sealed not less than 18 inches above the finished floor of the building to avoid fumes from the gasoline pumps. An approved seal must be installed on any conduit entering or leaving a dispensing pump or the enclosure on the pump island.

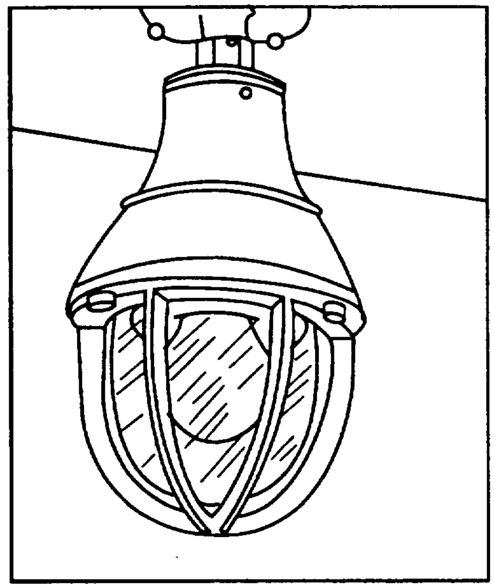
Inside the building of a gasoline station, the Class 1, Division 1, space extends 18 inches above the floor. Space above the 18-inch level is classed as Class 1, Division 2.

Paint spray booths are listed as Class 1, Division 1. Therefore all fixtures (exhaust fans, air compressors, or other electrical appliances) located in such booths must be explosionproof, as well as all switches, convenience outlets, and motor starters.



06NP0237

Figure 5-58.—Explosionproof fluorescent fixture.



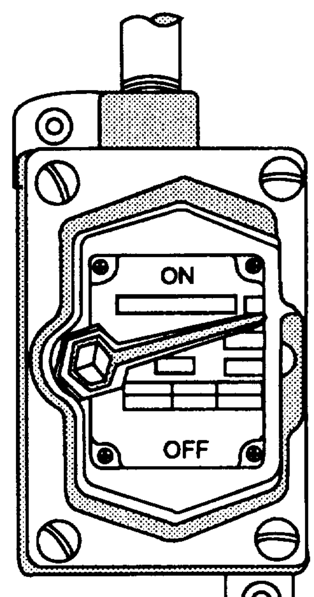
06NP0238

Figure 5-59.—Explosionproof incandescent fixture.

Figure 5-58 shows an explosionproof fluorescent lighting fixture for installation in a paint spray room. In this fixture, the fluorescent tubes are sealed in a larger glass tube. The four-tube seal ends can be seen in the figure. The ballast (explained in NEC© Article 410, Part P) is enclosed in the container above the tube seals.

Figure 5-59 shows an explosionproof incandescent lighting fixture; figure 5-60 shows an explosionproof on-and-off switch for lighting.

When the interior wiring system has been completely installed, make an overall inspection to be



06NP0239

Figure 5-60.—Explosionproof ON-and-OFF lighting switch.

sure that good installation practices have been observed and all connections are correct. While you are making this check, do not forget neatness. Make sure that ground connections are tight and that ground wire is protected against injury. Be sure that all connections in the entrance switch and panelboards are tight. See that all metal noncurrent-carrying parts of portable equipment are grounded

Panelboards

The service entrance terminates in the service equipment or in a panelboard. The panelboard may be used for lighting and power branch circuits. A distribution panel, as the name implies, serves as a center or point in the electrical system where power is fed to the branch circuits. A distribution panel consists mainly of a metal cabinet that houses bus bars and individual circuit protective devices. The protective devices (fuses or circuit breakers) protect me circuits against excessive current flow. Panelboards must be rated at least as high as the feeder capacity required for the load. Panelboards are marked by the manufacturer with the voltage, current rating, and number of phases for which they are designed. This information, plus the manufacturer’s name or trademark, is not to be obstructed by interior parts or wiring after the panelboard is installed. According to the NEC©, lighting and appliance panelboards cannot have more than 42 overcurrent devices besides the mains. Two-pole and three-pole circuit breakers are connected as two and three overcurrent devices, respectively.

According to the NEC©, each lighting and appliance panelboard must be protected from current flow on the supply side by not more than two main circuit breakers or two sets of main fuses that have a combined rating no greater than that of the panelboard. This protects not only the feeders but also the panelboard. The panelboard does not need individual protection if the panelboard feeder has overcurrent protection no higher than the panelboard rating. The total load on any single overcurrent device in a panelboard must not exceed 80 percent of its capacity where, in normal use, the load continues for 3 hours or longer to prevent overheating of the conductor.

Panelboard cabinets must be grounded. A terminal bar must be provided for attachment of feeder and branch circuit equipment-grounding conductors where nonmetallic raceway or cable is used. This terminal bar must be bonded to the cabinet, but not to the neutral bar except in service equipment.

Three-phase panelboards supplied by a four-wire, delta-connected system that has the midpoint of one phase grounded must have the higher voltage-to-ground conductor or bus bar marked. This high-voltage conductor should have an orange outer finish or be clearly tagged. The identification is required at any point where a connection can be made and the neutral conductor is also present. The phase arrangement on a three-phase panelboard is A, B, C, from left to right, or top to bottom when viewed from the front. The B phase will be the phase that has the higher voltage-to-ground.

There are two basic types of panelboards: fuse panels and circuit breaker panels. Fuse panels, as the name implies, contain fuses for protection of each circuit. Fuse panels are designed in a variety of ways. These designs vary in size, capacity (amperage and voltage), and type of installed fuses. The capacity of the panel is based on the ampacity of the bus bars of the panel. The number of bus bars is determined by whether the panel is single-phase or three-phase. Fuse panels are designed for plug fuses, cartridge fuses, knife-blade fuses, or a combination of these. Fuse panels use an Edison-base fuse that screws into a socket similar to the medium-based light socket. Fuse panels still exist but are not very common. Fuse panels are not to be installed either for new work or as a replacement panel unless they have been modified to accept Type S fuses. Refer to figure 5-61 for a view of the plug type of fuse and figure 5-62 for a view of the adapter and Type S fuse.

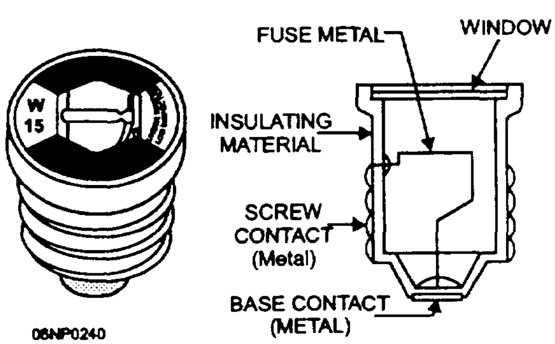


Figure 5-61.—Plug type of fuse.

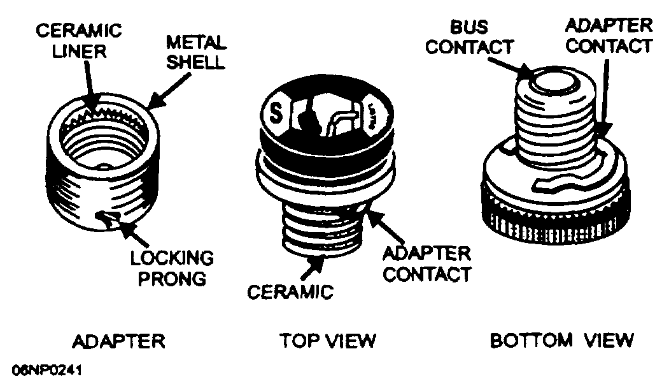


Figure 5-62.—Adapter and Type S fuses.

06NP0242

Figure 5-63.—Ferrule type of fuse.

060NP242A

Figure 5-64.—Knife-blade fuse.

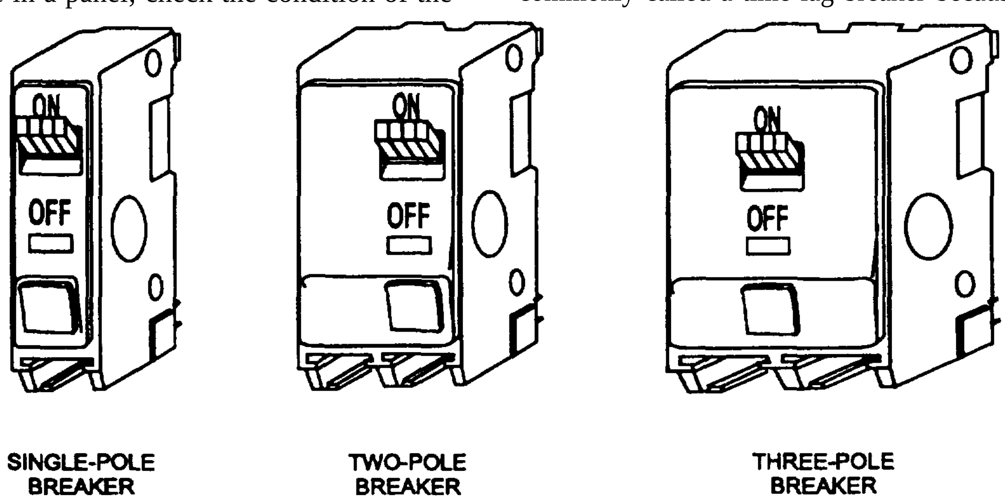
The other type of fuse you will be dealing with, as a CE, is the cartridge fuse. There are two types: the ferrule and the knife blade. Both types are available with replaceable or nonreplaceable fuse links. Ferrule fuses are available in ampere ratings from 0 through 60. Fuse panels that use the ferrule type of fuse have specially designed fuse clips in which only ferrule types will fit. Fuse diameter and length increase as amperage and voltage increase. Ferrule fuses are used in circuits up to 600 volts. Figure 5-63 shows a typical ferrule type of fuse.

Fuse panels that provide distribution for high-capacity circuits use knife-blade fuses for protection. The fuse clips are especially designed to receive knife-blade fuses only. Knife-blade fuses are available in ampere ratings of 61 through 6,000. The maximum voltage rating for knife-blade fuses is 600 volts. Figure 5-64 shows a typical knife-blade fuse.

Two factors must be considered when fuses for circuit protection are to be selected. These are the total current flow and the voltage of the circuit in which the fuse is to be installed. Since the purpose of the fuse is to protect the circuit, it must be the weakest point in the circuit. Thus the fuse used should be rated no higher than the lowest rated component to be protected. Before installing a fuse in a panel; check the condition of the fuse holder or clips. These must be clean and hold the fuse firmly.

One of the newer types of protective devices, used more often than fuses because of the way it reacts to an overload, is the circuit breaker. A circuit breaker trips on an overload but can be reset to complete the circuit again without having to be removed or replaced. Circuit breakers are classed according to their operating principle. They may be thermal, magnetic, or a combination of thermal and magnetic. Figure 5-65 shows typical circuit breakers with one, two, and three poles. Multipole breakers are designed to open all ungrounded conductors in a circuit at the same time.

A thermal type of circuit breaker has a bimetallic element within the breaker that responds to temperature change. The bimetallic element is made by fusing together two strips of dissimilar metal. Each strip has a different expansion rate when heated. Current flowing through the breaker generates heat, which increases as the flow increases. The heat causes the bimetallic element to bend and act against a latch. The breaker mechanism is adjusted so that when the current flow reaches a set level, the element bends enough to trip the latch. This action opens a set of contacts to break the circuit. The thermal type of circuit breaker is commonly called a time lag breaker because the breaker



06NP0243

Figure 5-65.—Typical circuit breakers.

does not open immediately when an overload occurs. The bimetallic element requires a short time (length depends on the size of the overload) to respond to the heat generated by the overload current.

A magnetic type of circuit breaker responds instantaneously when an excess of current flows through the breaker. A small electromagnet is used to actuate the breaker mechanism. Whenever a predetermined amount of current flows through the electromagnet, enough magnetic flux is created to attract a small armature. As the armature moves, the breaker mechanism trips and opens the circuit.

The thermal-magnetic circuit breaker, as the name implies, combines the features of both the thermal and the magnetic types. Of the three, the thermal-magnetic circuit breaker is preferred for general use. A small overload actuates the bimetallic strip to open the circuit on a time delay, while a large overload or short circuit actuates the magnetic trip to open the circuit instantaneously. Circuit breakers are rated in amperes and volts the same as fuses and you select them on the same basis. Circuit breakers are sealed units and no attempt should be made to repair them or to adjust the ampere capacity. A defective breaker must be removed and replaced.

Circuit breakers that are to be used in circuits that may pose an added hazard to the user are made with an extra safety feature. This breaker is called a ground fault circuit interrupter (GFCI). It is a thermal-magnetic breaker with an additional internal circuit that detects a current leak from the hot wire to ground and opens the breaker if that current reaches a set amount. This leakage cannot be more than 5 (±1) milliamperes (thousandths of an ampere) to ground. Most of these breakers have a test button that can be used to check the GFCI to see if it will trip when there is a fault.

To install the GFCI, you connect the circuit hot wire to the breaker the same as you do on a standard breaker. The circuit neutral is connected to another terminal on the GFCI instead of to the neutral bar in the panel. The GFCI comes with an attached white neutral wire, which you then connect to the neutral bar. The NEC© requires that GFCIs be installed for several circuits used in the home. These circuits include ALL 120-volt, single-phase, 15- and 20-ampere receptacles in bathrooms, garages, and outdoors. GFCIs may be used elsewhere when there is a need for the added protection.

Now that we have discussed the various types of panelboards, fuses, and circuit breakers, we need to discuss panelboard connections. Once the circuits have all been brought into the cabinet, the panelboard can be mounted in the cabinet. Also, the neutral bar and the equipment ground bar are attached to the cabinet. The ground bar must be bonded to the cabinet by either a bonding jumper or the more common method of running a screw through the bar into the cabinet. The equipment ground bar and the neutral bar are not bonded together unless the panelboard also serves as the service equipment.

Quite often the panelboard is not connected until the interior wiring is done and the receptacles, switches, and fixtures have been installed. The method of attaching circuit conductors is based on conductor size and type of terminals on the panelboard. Small conductors, No. 10 and smaller, are normally looped around a screw type of terminal. Larger conductors may need to have terminal lugs, attached so the connection can be made to screw terminals. Pressure types of terminals are often provided for larger conductors, neutral conductors, and equipment-grounding conductors.

Conductors should be connected in a neat and professional manner. In many cases, conductors are connected with little excess wire. Conductors brought in through the sides of the cabinet are connected directly to the overcurrent device. Those brought in from the top or bottom of the cabinet are bent neatly opposite the fuse or circuit breaker to which they are to be attached and cut just long enough to make a good connection, as shown in figure 5-66. However, many experienced electricians feel that this system of connecting conductors is not necessarily the best, even though it presents the most uncluttered look and leaves more space around each conductor. These electricians usually try to leave an end on each conductor that is equal to the height plus the width of the cabinet. Each conductor is run along the panel and looped back 180 degrees before being connected to its fuse or circuit breaker. This method is shown in figure 5-67. Little added material is needed, and the extra length on the conductor permits it to be switched to another terminal on the panel if desired. Also, in the case of conductor breakage near the terminal, the conductor can be reconnected easily.

The ungrounded conductors in a fuse panelboard are connected directly to terminals on the bus bars. In a circuit breaker panelboard, the underground conductors are usually connected to the circuit breaker. The circuit breaker is then inserted in the panelboard. In most cases, the breaker is snapped into place and is held by spring tension. Sometimes breakers are held in the panelboard by a screw.

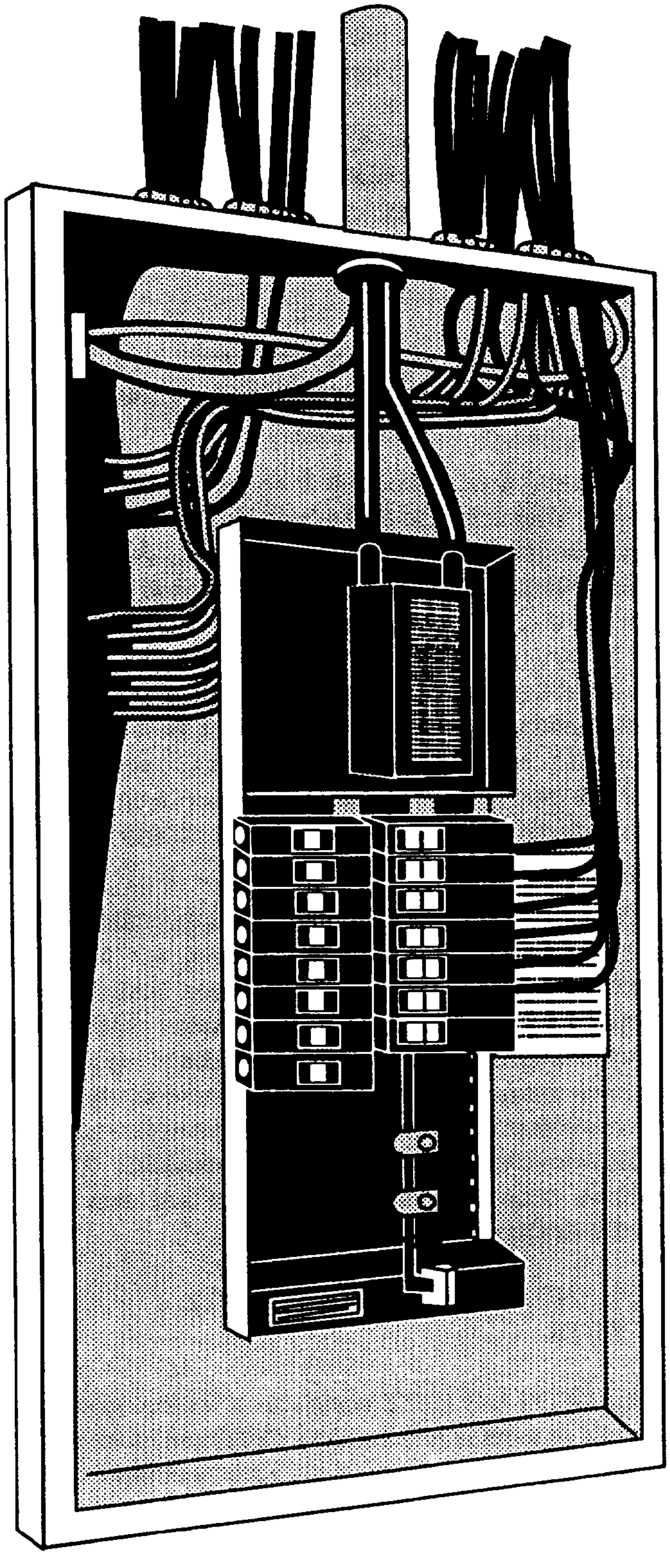


Figure 5-66.—Panelboard connections without excess wire.

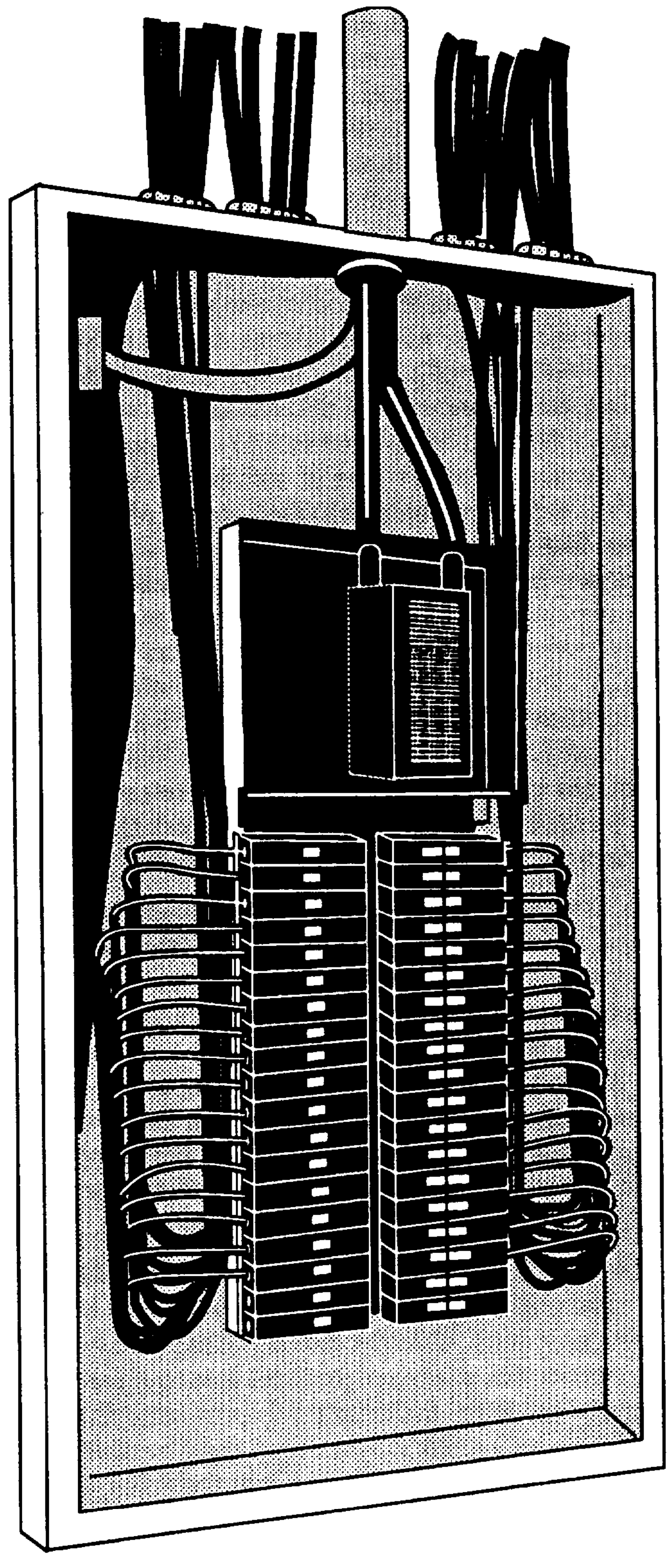


Figure 5-67.—Panelboard connections with leaped conductors.

Load Balancing

Now that you have installed the branch circuit conductors and breakers, you must balance the load. Conductors cannot be connected to a panelboard by attaching each one as you come to it. The arrangement or sequence of attaching conductors to the panelboard is determined by the arrangement of the bus bars in the panelboard, whether the circuits are 240 volts or 120 volts, and the need to balance the load on the phase conductors. Bus bars are installed into panelboards in one of several ways. Most of the time, the bus bars are run in a vertical configuration. In one arrangement, a split-bus panelboard is used that has all the 240-volt circuits in the upper section and the 120-volt circuits in a lower section. Another type of split-bus panelboard uses one main circuit breaker to feed one set of branch circuits and a second main circuit breaker to feed a second set. In many cases, panelboards are designed so that any two adjacent terminals can be used to provide 240-volt service. This arrangement also means that two 120-volt circuits attached to adjacent terminals are connected to different phase conductors. Since there are so many panelboard layouts, you must look at the panelboard to see how it is set up for 240-volt service, and you must be sure you get the conductors for 240-volt circuits connected to the proper terminals.

Loads that are connected to a panelboard should be divided as evenly as possible between the supply conductors. This process of equalizing the load is commonly referred to as load balancing. The purpose of load balancing is to reduce voltage drop that results from overloading one side of the incoming service. It also prevents the possibility of overloading the neutral. A perfectly balanced load between the supply conductors reduces current flow in the neutral to zero.

Load balancing is no problem for 240-volt circuits on a three-wire, single-phase system since the load has to be equal on each phase conductor. However, the 120-volt circuits are a different matter. These must be connected in such a way that the loads tend to equalize. Generally speaking, the simplest way to balance the load on a panelboard is to connect an equal number of branch circuits to each phase conductor. But this method does not necessarily give you a balanced load as will be evident if you will look at the top of figure 5-68. As you can see, the indiscriminate connection of branch circuits without consideration of their loads can cause you to end up with an unbalanced condition. On the other hand, you can connect the circuits so that one with a heavy load is offset by one with a light load, which does result in the balanced condition shown in the bottom of figure 5-68. Most of the time, you should be able to connect half of the lighting circuits and half of the appliance circuits to each phase conductor to give you a reasonably well-balanced load. Spare circuits should also be equalized There is one more thing to consider: When there are appliance circuits where the loads are known to be heavy, these circuits must be divided between the phase conductors.

TROUBLESHOOTING AND REPAIR OF INTERIOR WIRING SYSTEMS

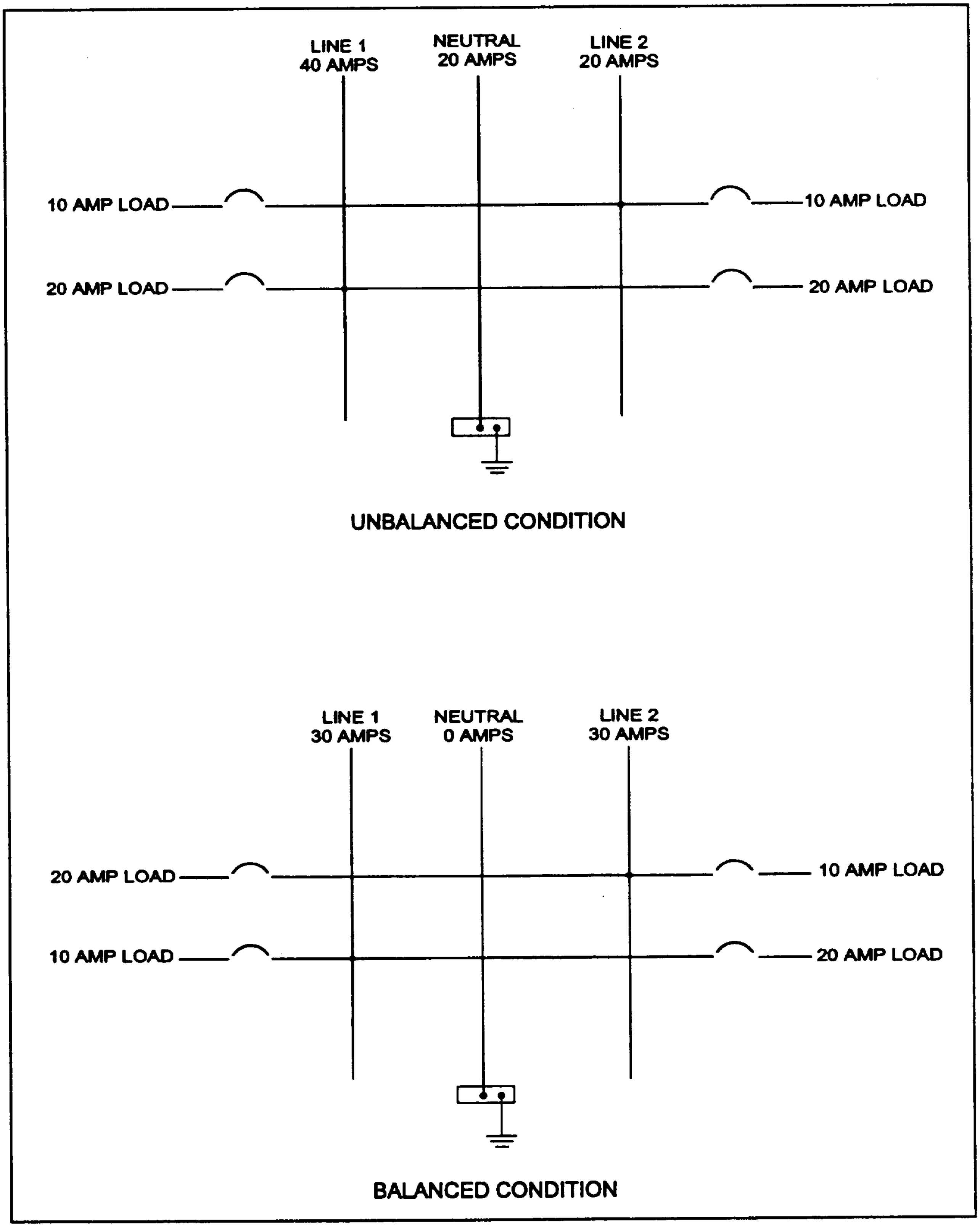
Electrical troubleshooting is an important part of your job. Your ability to find a faulty condition quickly can play an important part in shortening the downtime caused by failure. To find faulty conditions in circuits, you must do some inspecting, some calculating, and some instrument testing. A few moments spent studying the circuit diagrams before you start actual troubleshooting will simplify the task of isolating the trouble. If a circuit fails to function, use logic when you check for the fault. The trial-and-error method of finding faults in circuits is inefficient and time-consuming.

The first step to take in troubleshooting circuits is to inspect the circuit visually. Check for loose connections, loose wires, abraded wires, and loose fittings. An overloaded circuit is a serious problem. Many times the electrical demand on a circuit is so great that the circuit fuses blow or the circuit breakers trip. In some cases, the wrong fuses or circuit breakers are used, and the wires overheat and burn off the insulation. This condition causes shorts and grounds and sets up potential fire hazards.

OPEN, SHORTED, AND GROUNDED CIRCUITS

An OPEN CIRCUIT occurs in a wiring system when one or more conductors in a circuit are broken or otherwise separated. An open circuit is determined by the failure of a part or all of an electrical circuit to operate, even though the fuses may not be blown. Use the following maintenance procedures for locating the source of the trouble:

1. Initially, you should make a visual check for a broken or loose connection at the first dead (nonoperating) outlet in the circuit. If a defective connection is found, tighten or repair the connection.



06NP0246

Figure 5-68.—Load balancing.

2. If you do not find the trouble, or open, by a visual check, use a voltmeter to determine whether the circuit is live (operating) up to the point of the component.

A SHORT CIRCUIT results when two bare conductors of different potential come into contact with each other. If a conductor inadvertently contacts a metallic part of a wiring system, such as a motor frame or conduit, the system is sometimes said to be GROUNDED instead of having a short circuit. Grounds or short circuits can be (1) solid, (2) partial, or (3) floating. This situation presents a serious safety hazard because the machinery may be in operation, even though it has a short circuit. This condition is especially true in motors and some appliances.

A solid ground or short circuit is one in which a full-voltage reading is obtained across the terminals of a blown fuse when the load is disconnected from the circuit. The circuit resistance, in this case, is quite low, and the current is quite high so that the fuse will blow.

A partial short or ground is one in which the resistance between the phase wires, or between the phase wire and the ground, is partially lowered. However, enough current still remains to blow the fuse. Grounds of this type are generally more difficult to locate than are solid grounds.

A floating ground is a condition in which the resistance of the defect in a system varies from time to time. Grounds of this type may be present in an electrical system for some time before their existence becomes known. A floating ground is indicated when fuses are blown on the phase side of a circuit a number of times, and a circuit test shows no defects in the system. In grounds of this type, fuse trouble may not occur for several days. Then the ground recurs, and the fuses are blown again.

The procedures used to repair the troubles mentioned thus far are usually fairly simple. In the case of an open, short, or ground in NM cable, the bad section from box to box can simply be replaced using the same procedures outlined for installation. Another method would be to cut the cable at the trouble spot, install junction boxes, and add a short piece of cable to replace the bad section. Although the latter is the cheapest, it may not be possible if the trouble is concealed. Remember, you must have at least 6 inches of free conductor in a junction box to make the splices.

Once you find out where the trouble is in a conduit system, the repair procedure is even easier. All that is required is to pull the open, shorted, or grounded conductor out and replace it with a new one. This replacement can be done by attaching the new conductor to the one that is to be removed. In any case, a little common sense and knowledge of the NEC© requirements will dictate the action you should take.

METERS

Many times a visual inspection does not uncover an apparent problem; therefore, you must advance to troubleshooting with meters. In electrical troubleshooting, you will use voltmeters, ohmmeters, ammeters, and the meter that incorporates many meters—the multimeter.

When using a voltmeter, you have to connect the power to the circuit before testing. On the other hand, you cannot use the ohmmeter on an energized circuit. You need to start voltmeter tests at the power input end of the circuit, whereas you start ohmmeter tests at the ground end

Electrical circuit troubles develop either in the wiring or in the operating unit. If you analyze the problem carefully and take systematic steps to locate it, not only will you save much time and energy, but you will also prevent damage to expensive equipment.

Either dead circuits or live circuits can be tested with instruments. Circuit defects can sometimes be located more easily by one method than the other, depending upon the type of circuit and the trouble.

To test a dead circuit, disconnect the device from the outlet or disconnect switch. Equipment for this method of testing includes such units as ohmmeters and battery-powered test lamps. Asuitable continuity tester can be made easily from a flashlight in an emergency. An ohmmeter that contains its own batteries is excellent for continuity testing. A basic factor to consider in choosing continuity test equipment is to use relatively low-voltage instruments, reducing the danger of sparking.

WARNING

When connections are made in the presence of combustible vapors, sparking is a serious fire hazard.

When you test live circuits, energize the circuit under test from the power source. Generally, you will test with a voltmeter. Make certain that the voltmeter is designed for the type of current to be tested and has a scale of adequate range. Ensure that the circuit is disconnected from the power source before making the necessary circuit changes; then reapply the power.

WARNING

Be extremely careful not to touch the hot conductors when you use this method of testing because these live points of the circuit are exposed when the junction box covers are removed.

Let us troubleshoot a circuit with a voltmeter. The power to the circuit must be turned on. The first and most logical place to check is the fuse or circuit breaker panel. Set the voltmeter to the proper scale. If you do not know the value of the incoming voltage, set the meter to the highest scale; then work down to the proper scale. Check each incoming phase by connecting one lead of the voltmeter to the neutral and the other to each phase separately.

On a three-phase 120/208, 240-volt service, you must get 120 volts on each phase to ground. Less than 120 volts on one phase means that phase is open and you are getting a feedback from equipment connected to the lead side of the panel. Sometimes there will be a slight variation of normal voltage from the different phases; therefore, to determine if one phase is dead, check between the phases.

To perform this test, place one lead of the voltmeter on Phase A and the second lead on Phase B and read the voltage. It should read approximately 208 or 240, depending upon the system. After you have taken this reading, move the second lead to Phase C and take the reading. After this reading, move the first lead to Phase B and take the reading. You have now read between all phases and a lower than normal reading indicates an open phase.

Which phase is dead? Assume that Phase B has a blown fuse. When you take your reading between Phases A and B (fig. 5-69). you get a low-voltage reading. Your next reading, between Phases A and C, reads normal. But the next reading, between Phases B and C, again is a low reading. Each time you read to Phase B, you get low voltage. This reading is a good indication that Phase B is open.

Another way to determine which phase is open is to place one voltmeter lead on the top of the fuse and the other lead on the bottom of the same fuse. If you get a voltage reading across the fuse, that fuse is open.

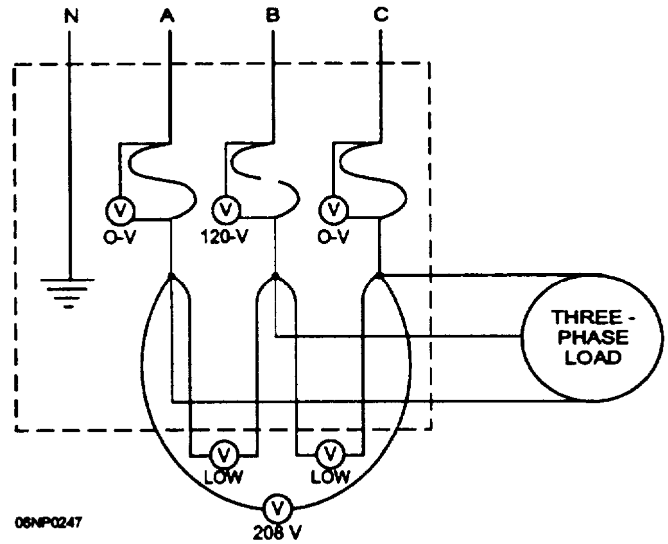


Figure 5-69.—Checking a three-phase circuit for a blown fuse.

Assuming that everything is all right at the main panel, let us examine a single 120-volt circuit. Illustrations help explain the procedure for locating an open in a circuit. Figure 5-70 shows a circuit with a lamp in series with a single-throw switch and fuse and the normal voltage readings at the various points of the circuit. If the lamp fails to light, check the circuit in progressive steps through the circuit and lamp from the last point where voltage is known to be present. In figure 5-71, we have voltage at one connection of the

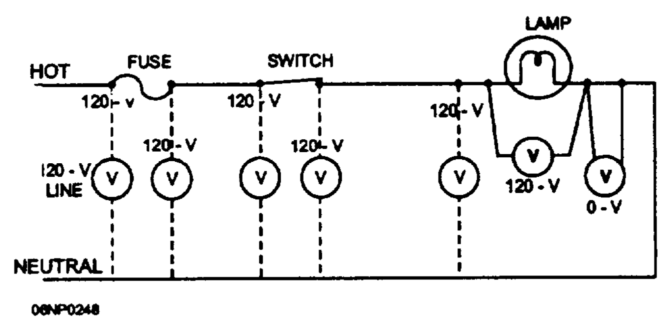


Figure 5-70.—Circuit with fuse, switch, and lamp.

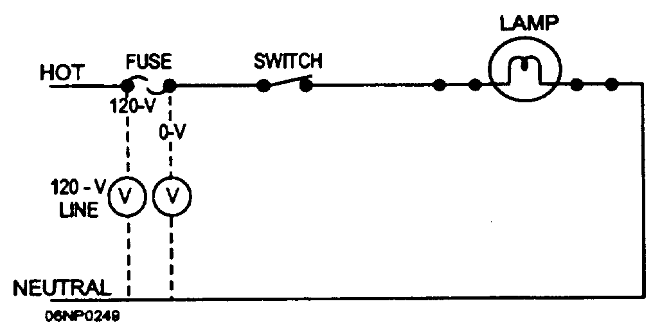


Figure 5-71.—Circuit with blown fuse.

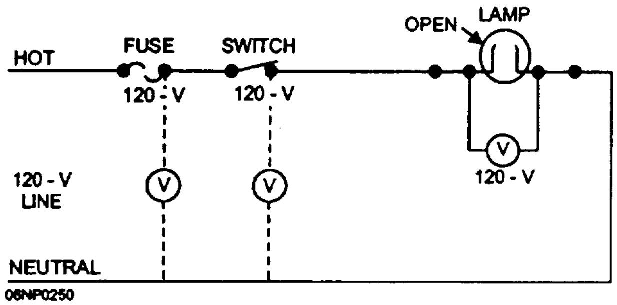


Figure 5-72.—Circuit with burned-out lamp.

fuse and no voltage at the other. Since the fuse is a conducting unit. normally the same voltage reading should occur between both sides of the fuse and the ground. The only conclusion in this case, then, is that the fuse is open.

Figure 5-72 shows that there is a voltage reading when the voltmeter is connected across the lamp. The logical assumption is that the lamp is inoperative. To be sure the lamp is inoperative, you must check it with an ohmmeter. Fuses, switches, and lamps are vulnerable; and you should check them first in a circuit.

In figure 5-73. the lamp does not light and the voltmeter shows voltage from the ground screw of the lamp to the neutral wire. These conditions indicate an open in the ground wire. When you connect the voltmeter at another point at the right of the lamp and no voltage is indicated, you can assume that there is an open in the wiring between this point and the lamp connection.

In figure 5-74, you find two lamps wired in parallel so that they can be controlled by a double-throw switch. With the switch in the OFF (center) position, there is no complete circuit, and neither lamp lights. When the switch is in the BRIGHT position, a circuit is completed

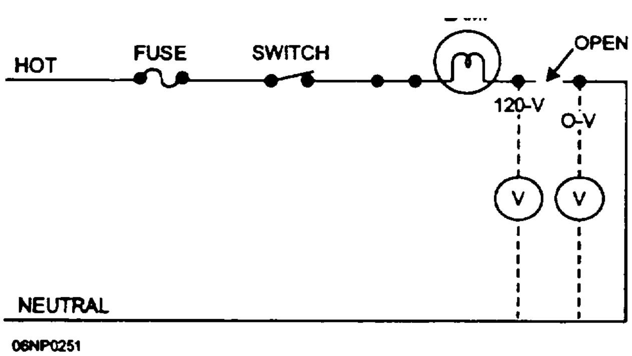


Figure 5-73.—Circuit with open in the wiring.

through the switch and through both lamps. With the switch in this position, the only resistance in the circuit is the resistance of the lamps. When the switch is in the DIM position, the circuit is completed through the lamps as before; but this circuit has an additional resistor in series with the lamps. This added resistance causes a decrease in current flow; therefore, the lamps glow with less intensity than before.

If one of the lamps lights and the other one does not, it is not necessary to check the complete circuit to find the open. The part of the circuit up to Point A is common to both lamps, and that much of the circuit must be completed for even one lamp to light. The place to begin checking the circuit is after Point A in the affected part of the circuit. In a circuit, such as the one shown in figure 5-74, it is best to use a voltmeter to locate the trouble. If you connect the negative lead of the voltmeter to the ground and the positive lead to Point A, you will get a reading on the voltmeter scale because Point A is connected through the switch to the positive line wire. If the positive lead of the voltmeter is moved in succession from A to B to C, you are able to check the continuity of wires AB and BC. If the check at Point C reveals no voltage, this condition indicates that wire BC is open.

You can make this same check with an ohmmeter, but several additional steps are required. First, remove power from the circuit by placing the circuit breaker and circuit switch in the OFF position. Next, disconnect the junction of wires at Points A and C. Then, with one ohmmeter lead placed on the loose wire at A and the other one on B, check the continuity of the wire. When this check is made and the ohmmeter indicates a low resistance, you have continuity in the wire. But if you place one ohmmeter lead on B and the other on the disconnected wire at C and you get an infinite resistance, there is an open in the wire.

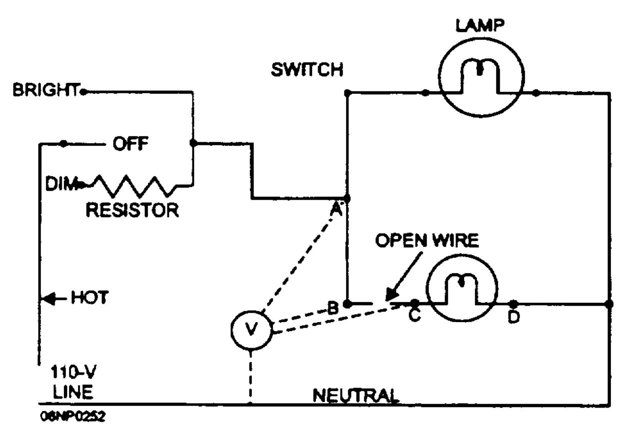


Figure 5-74.—Troubleshooting an open circuit with a voltmeter.

WARNING

For your safety, before you begin testing with an ohmmeter, BE SURE that the circuit that you are about to test is de-energized. Isolate the circuit being tested to prevent reading resistance from other circuits.

Many times you can determine the approximate location of an open by simply studying the circuit diagram before doing any actual circuit testing. For example, suppose both lamps in figure 5-74 light when the circuit switch is placed in the BRIGHT position, but neither lamp lights when the switch is placed in the DIM position. Because the lamps light when the switch is in one position, you can gather that all wires and lamps are good. The only units that could be faulty are the resistor, half of the switch, or the wires that connect the switch and the resistor. By using the ohmmeter as you did before, you can check the continuity of these parts.

A short circuit exists when there is a direct connection between two wires or conductors of different potentials. If the trouble is not found by a visual inspection, you must isolate it step by step. First, disconnect all the equipment in the circuit and install a new fuse or place the circuit breaker to the ON position. If the short is clear, then the trouble will be found in the equipment. However, if the short circuit does not clear and the fuse burns out again or the circuit breaker trips, then the trouble is in the wiring.

To find the short in the electrical wiring, you first disconnect the wires at both ends of the circuit and test each wire with an ohmmeter.

If there is a short between the wires, a low-resistance reading will appear on the ohmmeter. If no short exists between the wires, a high-resistance reading will appear on the ohmmeter. You should continue this procedure until the short is found.

Let us assume that a light circuit is faulty. Using figure 5-75 as an example, you see a circuit with three lights controlled by a switch with a short at the junction box of the middle lamp. Disconnect the wires at the fuse panel to isolate the circuit and to prevent feedback from the other circuits.

Connect one lead of the ohmmeter to neutral and the other to the wire you have just disconnected. With the switch open, the ohmmeter will read infinity. Closing the switch will cause the ohmmeter to read continuity, showing that the short is beyond the switch. You can now proceed to the nearest junction box and test at the first light. Remove all light bulbs from the circuit.

Disconnect Point A and connect the ohmmeter between the neutral and the wire leading to the first

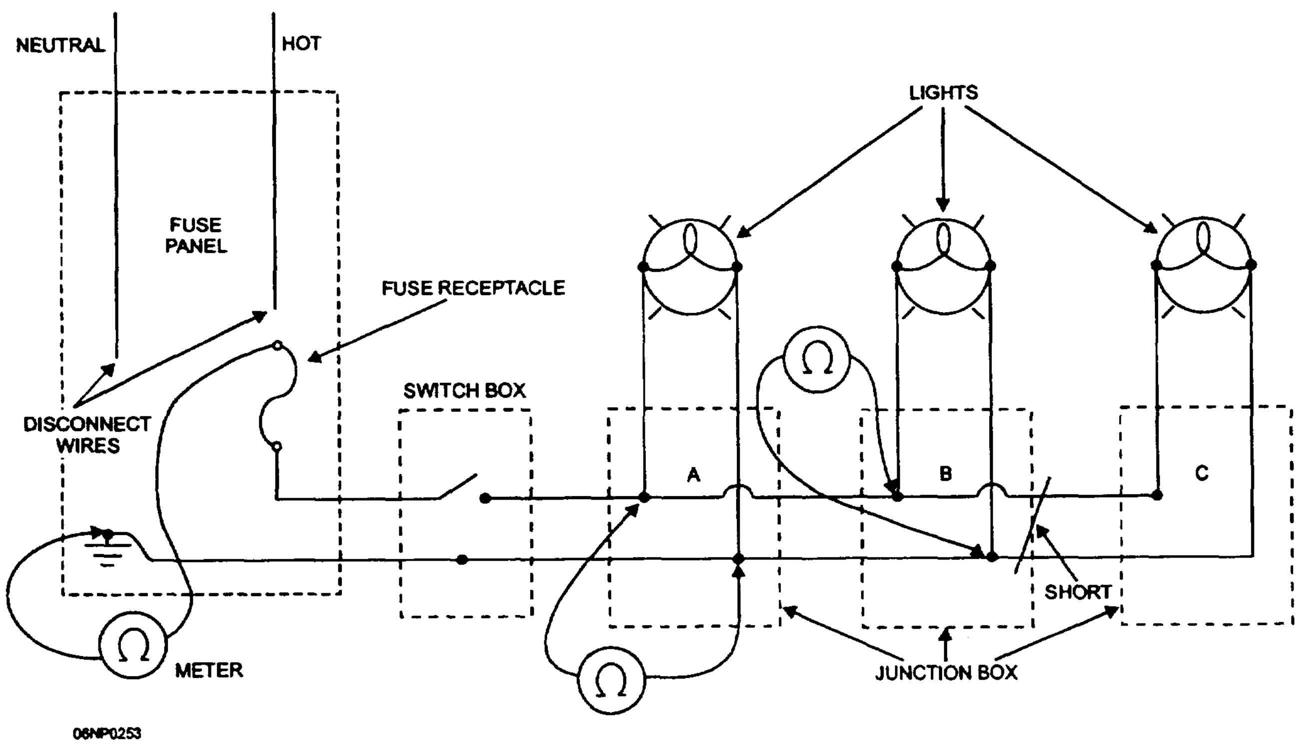


Figure 5-75.—Faulty lighting circuit.

lamp. You will read infinity. Remember, "infinity" means that the circuit is good, and "continuity" means a short. Now, connect the ohmmeter between the neutral and the lead going to the middle lamp. The reading will show continuity, indicating the short is beyond Point A. You should leave Point A open at this time and continue on to the middle lamp.

Disconnect Point B and take the same readings that you took at the first light. From these tests you can determine that the circuit between the first and middle lamp is all right (infinity reading), and the trouble must be between the second and third lamp. By checking closely at the middle junction box, you can probably see charred or frayed wires indicating the problem. You may need to continue your check to Point C. Use the same procedure as with the other lamp, and find the trouble between Points A and C.

LIGHTING

After installing the switches needed to control the lighting, you need to mount the light fixture itself. Each lighting installation is designed to produce a specific level of illumination adequate for those working in the area. The amount of illumination initially provided starts to decline almost as soon as it is put in operation. This reduction is caused by dirt on the lamps and luminaries, a decrease in lamp lumen output, and dirt on the room walls and ceilings. Illumination should be sufficient to eliminate eyestrain, support a high level of production, and promote safety and employee morale.

Lighting fixtures are designed for a particular lamp size and type. Many fixtures, however, were installed in military buildings long before the manufacturers started producing higher and higher wattage lamps in ever smaller envelopes. Consequently, it is possible to use much higher wattage lamps than the fixture or the circuit can handle adequately.

CAUTION

Excessive heat of higher wattage lamps can damage the sockets, increase failure rate, and overload the circuits. Personnel are cautioned to use only the lamp size (in watts) recommended for the fixture, rather than a higher wattage lamp that may physically fit.

INCANDESCENT LAMPS

Incandescent lamps come in a variety of voltage ratings. For most applications, the lamp voltage rating nearest the available line voltage should be selected. Under this condition, the lamp will produce its rated values of life, watts, and light output. Many incandescent lamps are available with life ratings considerably in excess of ordinary general service lamps. Some have ratings of 5,000 hours or more, and some even are guaranteed to burn for 5 years. General use of these lamps is not recommended because the initial cost is comparatively high and the extended life is gained by reducing the light output. There are, however, a few areas where it is necessary to use bulbs with a long life. Typical locations include high-ceiling auditoriums, exit lights, stairwells, and marker lights on towers or fire alarm boxes. For these areas, do not use a special rated lamp. Do use an ordinary general service lamp whose voltage rating is higher than the circuit voltage; for example, 130-volt or higher lamps for 120-volt circuits. When you are operating the lamp below its rated voltage, the life is increased at a sacrifice in light output. For general use, the lamp voltage rating nearest the available line voltage should be used.

Many kinds of incandescent lamps are especially designed for placement in a variety of situations; for example, under severe physical conditions (such as vibration or extreme temperatures), in inaccessible locations, or when special lighting effects are desired. Some of these types of incandescent lamps and their uses are as follows:

INSIDE-FROSTED LAMPS are used in most fixtures designed for incandescent lamps. The frosted finish reduces lamp brightness and glare.

CLEAR LAMPS are used in fixtures where control of the light is required (such as in reflectors having polished reflecting surfaces and in enclosed globes or reflectors of prismatic glass), particularly where concentrated light control is required, as in high, narrow bays.

Reflector equipment of the diffusing globe type, where the lamp protrudes through the bottom of the fixture, requires WHITE BOWL LAMPS. The white bowl reduces the surface brightness and glare from the working surfaces.

SILVERED-BOWL LAMPS are used principally for indirect lighting and in reflector equipment. The fixture parts should not touch the lamp as the thermal expansion may cause the bulb to crack and fail prematurely.

REFLECTOR LAMPS with the reflecting surface inside the lamp are, in effect, a fixture in themselves. A collection of dust and dirt on the exterior of the lamps can cause them to lose their effectiveness.

PROJECTOR LAMPS are installed in indoor and outdoor display lighting fixtures. They use a self-contained reflector but have an advantage over the reflector type since they are suitable for extreme temperature conditions and provide more accurate light control.

HEAT AND DRYING LAMPS, available with built-in reflectors or with separate reflectors, are an inexpensive answer to a requirement for instantaneous infrared energy. The reflector bulb keeps the initial cost to a minimum and provides a new reflecting surface with each new lamp.

HARD-GLASS LAMPS, made of special glass with high resistance to thermal shock, are effective where rain, splashing liquids, insects, snow, fixture parts, or hot metallic spray may touch the glass bulbs.

VIBRATION SERVICE LAMPS are available that withstand excessive vibration that cannot be eliminated by flexible fixture mounting.

Where the lamp will be subjected to shock, such as at the end of a drop cord or near machinery, you will want to select ROUGH SERVICE LAMPS. With filament supports, these lamps can withstand severe shocks without failure.

High-cost replacement areas, such as towers, industrial high bays, theater marquees, halls, and stairwells, are lighted with LONG-LIFE LAMPS.

QUARTZ-IODINE LAMPS offer a concentrated source of incandescent light with excellent light control characteristics, good color, and a life twice that of regular general service incandescent lamps. They depreciate at a lower rate than the general service lamp. The lamp cost is considerably higher, however, than a general service lamp, and a special fixture is required.

FLUORESCENT LAMPS

There are two principal types of fluorescent lamps: instant-start and rapid-start preheat lamps. Both have practically the same physical dimensions but different internal construction. The type of circuit in which the lamp should be used is etched on the end of the lamp. The rapid-start preheat lamp operates satisfactorily with either the preheat or rapid-start circuits. It has a short lamp life in an instant-start circuit. The instant-start lamp operates satisfactorily with an instant-start ballast, burns out the ballast in a rapid-start circuit, and does not light in a preheat circuit. Preheat lamps dominated the field for many years but are no longer considered a major type. They continue to be in use, however, particularly in fixtures using lamps smaller than 40 watts.

Examples of circuits for the major types are readily found in current manufacturers' publications. Example of some circuits are shown in figure 5-76. The 4-foot rapid-start lamp is the preferred lamp for most applications.

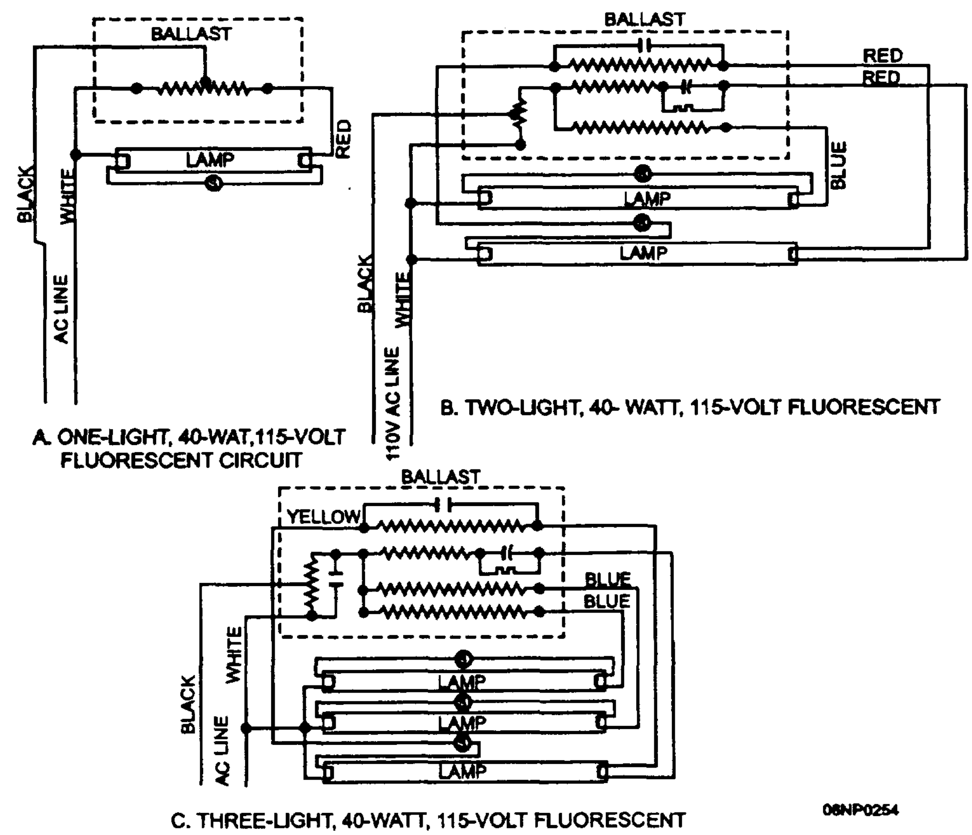


Figure 5-76.—Representative fluorescent circuits.

Fluorescent lamps are available in a variety of colors for decorative use as well as numerous shades of white for general illumination. The predominant white shade recommended for most office areas is cool white. Other shades of white used for various purposes include daylight, deluxe cool white, white, warm white, and deluxe warm white. Daylight and cool white provide a crisp, cool, businesslike atmosphere, and the warm whites find application in restaurants, homes, theaters, and similar areas. The appearance of colored materials will be better under a fluorescent light that contains a high component of the same color. Blue backgrounds improve with the cool whites and daylight. Deluxe warm whites strengthen oranges and yellows.

Fluorescent lamps require ballasts to limit the current and to supply proper voltage to start and to operate the lamps. For general lighting purposes, the ballasts also contain a capacitor to improve power factor. The NEC© requires that all indoor fluorescent fixtures (except those with simple reactance ballasts) incorporate ballasts with thermal protection. The thermal protector isolates the ballast and fixture from the circuit in the event of overheating. As a result, damage from fires and from leaking compounds should be reduced. There are small fuses available that can be installed in the fixture to provide this protection for existing ballasts.

MERCURY LAMPS

Mercury lamps (fig. 5-77) have the best maintained light output because the electrodes operate at a relatively cool temperature, resulting in less evaporation of the metals and oxides. The clear mercury lamp has a better lumen maintenance than those with phosphor coating. Long average life (16,000 hours and up) is a primary characteristic of most mercury lamps. There will be a different economic life for mercury lamps at each installation, depending on lamp mortality, power cost, equipment and wiring costs, frequency of replacement and cleaning of lamps, and other factors. Mercury lighting is one of the most economical means of lighting high- and medium-bay industrial areas, particularly in areas where color rendition is not critical. Small wattage lamps have been introduced, and it is anticipated that future designs will see a more widespread use of these in low-ceiling nonindustrial areas. An objectionable characteristic of mercury lamps is the time required to reignite (several minutes) after a momentary loss of power.

CAUTION

While the lamp bases are the same size as incandescent lamps, mercury lamps must never be'used to replace a burned-out incandescent lamp because a ballast must be used with mercury lamps.

METALLIC-VAPOR LAMPS

Metallic-vapor lamps resemble mercury-vapor lamps in appearance and have similar uses. The initial efficiency and control are better with metallic-vapor lamps than with mercury-vapor lamps. In regard to disadvantages, the rate of depreciation is much greater with metallic than with mercury, the cost is higher, and the life expectancy is shorter.

High-pressure sodium-vapor lamps are used for highway interchanges, parking lots, and high-bay industrial areas. They are the most efficient of the light sources in general use in number of lumens produced per watt of electricity. The relative cost is high, the life ratings are not well established, and a special ballast is required. The color is slightly yellowish

OVERALL ILLUMINATION

Walls, ceilings, and surroundings are an important part of the overall illumination system since they redirect light to the working area. The most efficient lighting system is obtained when the fixtures are new and when the walls, ceilings, floors, and furnishings of

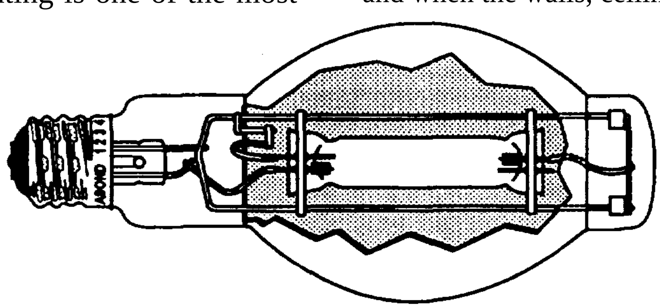


Figure 5-77.—Mercury lamp.

the room are colored with a high-reflectance color. Lighting is, however, only one of many factors that make up the whole environment. While the highest lighting efficiency may be maintained in a completely white room, the psychological effect of such surroundings on the occupants may be less than harmonious. The use of color in the surroundings, even if it means sacrificing lighting efficiency, is necessary for the well-being of the occupants. Ceilings should have the lightest color, preferably an off-white. Shiny surfaces should be avoided, as they result in glare. As mentioned earlier, lighting levels start dropping immediately after the installation of the fixtures. Lamp burnouts and lamp depreciation contribute to this, but the principal cause is the accumulation of dirt. It is not uncommon to find lighting levels one half of the initial values after only a year or so of operation. The lighting maintenance program must include cleaning and painting of the walls and ceilings in addition to the fixture cleaning schedule.

When mounting any light fixture, follow the manufacturers' step-by-step instructions. The most important thing to remember when mounting any fixture or device is to ensure that all connections are both electrically and mechanically secure.

High-intensity discharge lamps (HID) will be discussed further in chapter 6.

TROUBLESHOOTING LAMPS

As light sources are designed to operate most efficiently and economically at their rated voltages, special emphasis should be given to using lamps to suit the voltage of the circuit. Operation within the normal operating range is desirable; because both overvoltage and undervoltage operations have a determined effect on the life, efficiency, and economy of the light source. The effect on lamps operated over or under their rated voltage range is described below.

FLUORESCENT LAMPS

Line voltage higher than the maximum of the ballast range will shorten lamp and ballast life. Line voltage below the minimum range will reduce illumination and may cause uncertain starting of some types of fluorescent lamps.

INCANDESCENT LAMPS

Line voltage higher than the maximum lamp range will increase the light output but will shorten lamp life. Line voltage below the minimum range will extend lamp life but will reduce light output approximately 3 percent for each 1 percent in voltage drop.

MERCURY LAMPS

Line voltage higher than the maximum lamp range will shorten lamp and ballast life. Line voltage below the minimum range will reduce illumination and may cause uncertain starting.

LAMP GUIDES

The most common troubles encountered with lamp equipment, the probable causes, and the suggested solutions are contained in table 5-6.

MAINTENANCE OF LIGHTING SYSTEMS

Lighting has a great influence on the quality and quantity of work as well as a direct bearing on employee morale. The necessity for periodic attention to the lighting system cannot be overemphasized. To prevent progressive deterioration of the system, personnel must provide regular maintenance and prompt repair of any deficiency.

Maintain the required illumination intensity by keeping lamps, fixtures, and reflective areas clean and in good repair; by replacing defective lamps; and by keeping the voltage steady.

It is well known that dirt absorbs and masks light. The progressive decrease of light caused by accumulating dirt renders periodic cleaning of lighting equipment a necessity. The frequency of cleaning depends largely upon local conditions. Fixtures in air-conditioned and air-filtered rooms may require cleaning only once a year. In an atmosphere that is heavy with dust and fumes, cleaning every few weeks may be necessary.

The cleaning schedule for a particular installation should be determined by light meter readings after the initial cleaning. When subsequent foot-candle readings have dropped 20 to 25 percent, the fixtures should be cleaned again. Readings should be made with the light meter at the working surface with the meter reader in the position of the operator or person using the working surface.

Lighting equipment should be washed, not just wiped off with a dry cloth. Washing reclaims 5 to 10 percent more light than dry wiping and reduces the possibility of marring or scratching the reflecting surface of the fixtures.

To clean removable glassware, reflectors, and diffusing louvers, immerse them in a solution of

Table 5-6.—Lighting Maintenance Chart

INCANDESCENT

SYMPTON	POSSIBLE CAUSE	REMEDY
Lamp out, but defective	Loose lamp, or loose or broken connections.	Tighten in socket, or secure terminals, or repair wiring.
Lamp burns dim	Low voltage	Match lamp rating to line voltage. Increase line voltage.
Short lamp life	High voltage, or bulb cracked, or incorrect lamp, or excessive vibration.	Match lamp rating to line voltage and reduce voltage. Replace lamp. Replace with lamp of proper rating. Use shock-absorbing device.
Lamp breakage	Water contracts lamp bulb, or bulb touches luminaire.	Use in closed, vaportight luminaire if water vapor is present. Seal joint where conduct stem enters luminaire. Use correct-size lamp. Straighten socket.

FLUORESCENT

SYMPTON	POSSIBLE CAUSE	REMEDY
Lamp does not start or flashed on and off	Lamp pins not contracting, or lamp worn out, or starter defective, or low line voltage, or fault in circuit or luminaire.	Seat lamp firmly and correctly. Replace with tested lamp. Replace with tested starter. Check with voltmeter. Check wiring and lamp holders. Check ballast
NOTE: A flashing lamp usually indicates end of lamp life.		
Lamp flickers: ARC wiggles, swirls or flutters.	Defect which occurs in both new and old lamps.	Turn luminaire on and off several times. Allow a new lamp to operate a few hours for seasoning. Remove lamp and shake one end down. Replace lamp if flicker persists. If flicker is repeated in new lamp replace starter.
Lamp starts slowly (should start in a few seconds)	Low line voltage or slow starter.	Check with voltmeter. Replace starter.
Short lamp life (A few early failures do not indicate average for group. Some fail after a few hundred hours; others last 4000 - 6000 hours.)	Low line voltage, or lamps turned on and off too often	Check with voltmeter.
Radio interference	May originate from other source. Radio too close to lamp. Aerial lead-in not shielded.	Operate radio with fluorescent lamps turned off. Move radio 9 to 10 feet from lamp. Shield lead-in and ground shield. Install filter radio or luminaire.
Noise from ballast. (Don't expect perfect silence)		If quiet necessary, take special precautions in locating ballast. If unit very noisy, replace ballast..

MERCURY LAMP

SYMPTON	POSSIBLE CAUSE	REMEDY
Lamp fails to start	Lamp loose.	Tighten in socket.
	Lamp burned out.	Replace.
	Low voltage.	Increase lamp voltage by changing transformer tap.
	Wiring fault.	Check wiring. Tighten connections.
	Low temperature.	Lamps may not start when temperature is below 32 F. °
	Fluctuating voltage.	Check line voltage. (Momentary dips of 10 percent, or more, often cause light to go out.)
Lamp frequency goes out	Wiring fault.	Tighten connections. Check wiring. Separate lighting circuits from heavy power circuits.
Annoying stroboscopic effect	Cyclic flicker.	Where there is a 3-phase supply. Connect luninaires on alternate phases. On single-phase, add incandescent luminaires to the system.

06np0256

synthetic detergent cleaner and scrub them with a soft brush or sponge. When incrustation is not removed by scrubbing, use No. 0 steel wool to remove dirt film. Rinse in warm, clear water and dry with a clean cloth.

CAUTION

Do not immerse lamp base or electrical connections in the cleaning solution.

Glassware, reflectors, and diffusing louvers that cannot be removed should be cleaned as follows:

Wipe with a moist cloth or sponge, using a solution of synthetic detergent cleaner. When incrustation is not removed by sponging, use No. 0 steel wool to remove dirt film. Take care to ensure that shreds of steel wool do not touch the pin contacts or get into the lamp socket. Wipe off excess moisture with a clean cloth. Clean fixture holders and stem hangers with a moist sponge or cloth dampened with synthetic detergent cleaner and wipe dry. Enameled, chrome, aluminum, or silver-plated reflecting surfaces that cannot be adequately cleaned and polished should be replaced.

Neglected lamp outages reduce illumination. If burned-out lamps are not promptly replaced, illumination may drop to unsafe foot-candle levels in a short time because of outages alone. In some cases, it may be satisfactory and more economical to clean lamp surfaces and fixture interiors only at the time of relamping. Each activity must determine whether cleaning is to be accomplished by electrical, self-help, or custodial service personnel.

Burned-out lamps are replaced on request. To prevent reduced illumination from lamp outages, do the following:

- Instruct employees to report burnouts as they occur.

- Replace blackened or discolored lamps, even though they are still burning. Discoloration indicates the lamp is nearing the end of its useful life.

- Replace fluorescent lamps as soon as they begin to flicker. A burned-out lamp in a live circuit may cause damage to starter and ballast. Blackening at the ends of the tube adjacent to the base indicates that the lamp is near the end of its useful life.

- In general, replace with the same type, wattage, and voltage as that of the lamp removed. If frequent burnouts occur, the voltage rating of the lamps may be too low. Lamps of higher wattage than called for on lighting design plans should not be used.

SCAFFOLDING

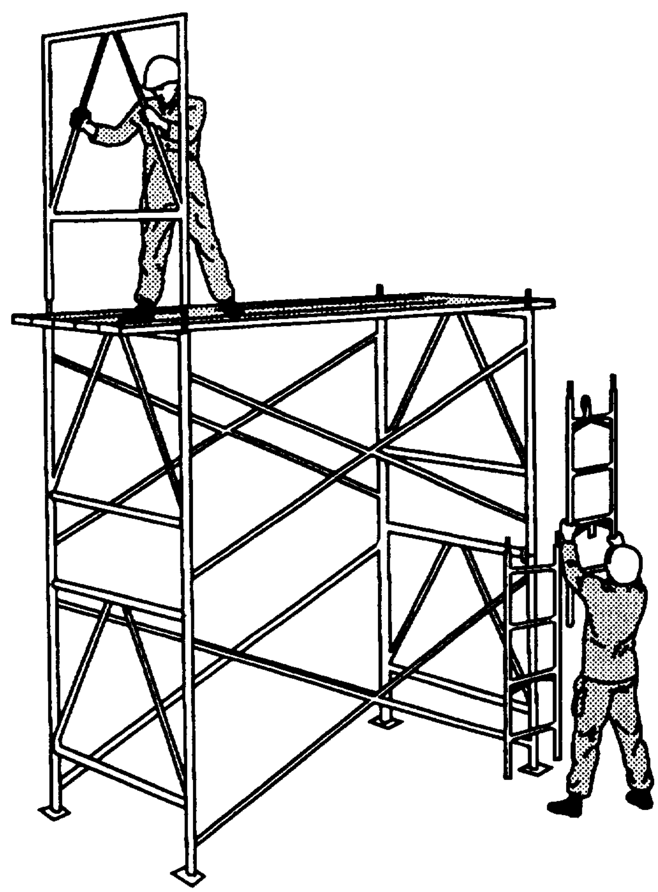
As the working level of a structure rises above the reach of crew members on the ground, temporary elevated platforms, called SCAFFOLDING, are erected to support the crew members, their tools, and materials.

There are two types of scaffolding in use today: wood and prefabricated. The wood types include the swinging scaffold, which is supported on the ground. For information concerning the wood type of scaffolding, refer to *Builder 3 & 2*, volume 1, NAVEDTRA 12520, chapter 4. The prefabricated type is made of metal and is put together in sections as needed. As a CE, you will be working more with the prefabricated type of scaffolding.

This section provides only general information on prefabricated scaffolding. For further details of scaffolding, consult the latest copy of the Code of Federal Regulations (29 CFR 1926).

PREFABRICATED SCAFFOLDING

Several types of patent-independent scaffolding are available for simple and rapid erection, as shown in figure 5-78. The scaffold uprights are braced with



06np0257

Figure 5-78.—Assembling prefabricated independent-pole scaffolding.

diagonal members, as shown in figure 5-79, and the working level is covered with a platform of planks. All bracing must form triangles, and the base of each column requires adequate footing plates for bearing area on the ground. The patented steel scaffolding is usually erected by placing the two uprights on the ground and inserting the diagonal members. The diagonal members have end fittings that permit rapid locking in position. The first tier is set on steel bases on the ground. The second tier has the bottom of each upright locked to the top of the lower tier. A third and fourth upright can be placed on the ground level and locked to the first set with diagonal bracing. The scaffolding can be built as high as desired, but high scaffolding should be tied to the main structure.

Steel and aluminum scaffolding is used to speed up construction and maintenance operations. Many types are available for interior work and erection. This kind of scaffolding is used around many construction sites because it can be disassembled and transported whenever necessary. The scaffolds are mounted on steel casters with brakes and adjustable supports, which permit quick movement and positioning of each tower This scaffolding is equipped with special trussed planks, 12 feet long, that are placed to enable crew members to be within comfortable and safe working distance of all working space.

Prefabricated scaffolding of this type comes in three categories: light, medium, and heavy duty. Light-duty scaffolding has nominal 2-inch-outside-diameter steel-tubing bearers. Posts are spaced no more than 6 to 10 feet apart. The load it can handle is 25 pounds per square foot. Medium-duty scaffolding normally uses 2-inch-outside-diameter steel-tubing bearers. Posts should be spaced no more than 5 to 8 feet apart. If 2 1/2-inch-outside-diameter steel-tubing bearers are used, posts are spaced 6 to 8 feet apart. The load it can handle is 50 pounds per square foot. Heavy-duty scaffolding should have bearers of 2 1/2-inch-outside-diameter steel tubing with the posts spaced not more than 6 feet 6 inches apart. The load it can handle is 75 pounds per square foot.

To find the load per square foot of a pile of materials on a platform, divide the total weight of the pile by the number of square feet of platform it covers.

SAFETY

The following safety precautions must be observed by all persons working on scaffolds or tending other persons who are working on scaffolds. Construction

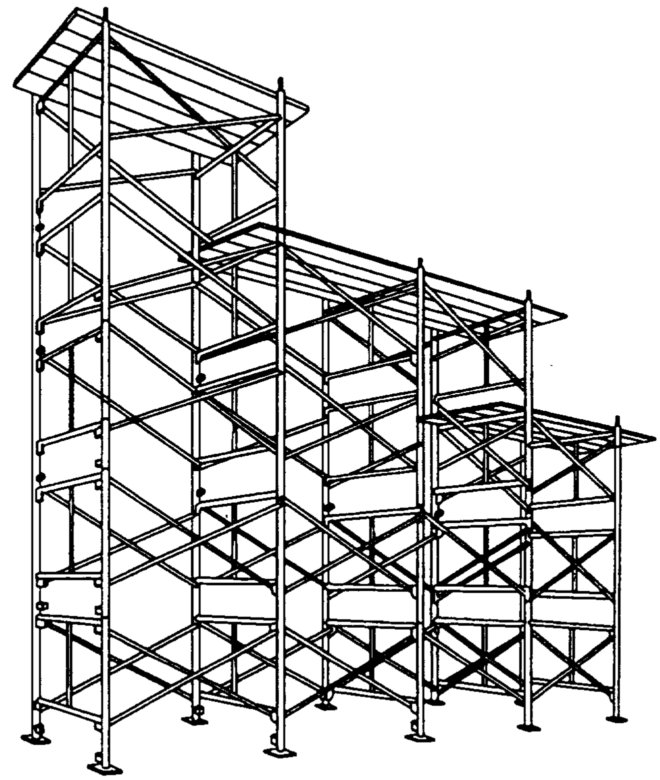


Figure 5-79.—Prefabricated independent-pole scaffolding.

Electrician petty officers must not only observe the safety precautions themselves, but they must also issue them to their crew and ensure that the crew observes them.

- Scaffolds must be kept clear of accumulations of tools, equipment, materials, and rubbish.

- No scaffold may be used for the storage of materials in excess of those currently required for the job.

- Tools not in immediate use on scaffolds must be stored in containers to prevent tools left adrift from being knocked off. Tool containers must be lashed or otherwise secured to the scaffolds.

- Throwing objects to or dropping them from scaffolds is absolutely prohibited. Hand lines must be used for raising or lowering objects that cannot be passed hand to hand

- A standard guardrail and toeboard should be provided on the open side of all platforms 5 feet or more above ground; otherwise, safety belts tied off to safety lines must be used.

- No person should remain on a rolling scaffold while it is being moved.

- All scaffolds must be maintained in safe condition, and they must not be altered or disturbed while in use. Personnel must not be allowed to use damaged or weakened scaffolds.

- Access to scaffolds must be by standard stairs or by fixed ladders only.

- When scaffolding is being dismantled, it should be cleaned and made ready for storage or use. Scaffolding that is not ready for use should never be stored.